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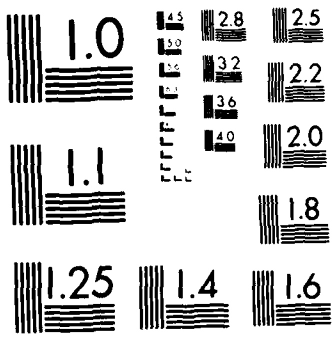

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AD-A153 511

THE DEPARTMENT OF DEFENSE
REPORT ON

SELECTED UNIVERSITY LABORATORY NEEDS IN SUPPORT OF NATIONAL SECURITY

PREPARED FOR THE SUBCOMMITTEE ON
RESEARCH AND DEVELOPMENT OF
THE COMMITTEE ON ARMED SERVICES OF
THE UNITED STATES
HOUSE OF REPRESENTATIVES

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CHAPTER I

INTRODUCTION

A. RATIONALE

The Report of the House Armed Services Committee on the 1984 Department of Defense Authorization Act contained the following request: "Many of the university laboratories in which Department of Defense research programs are conducted are obsolete and in need of major modernization or replacement. The committee believes a study should be undertaken on the need to modernize university laboratories in the physical sciences, earth and ocean sciences, atmospheric sciences, engineering, computer sciences and other fields essential to our long-term national security. The survey should (1) document the laboratory needs of universities presently engaged in Department of Defense competitive research programs, (2) assess priorities by academic field, (3) provide estimates of costs to meet these needs, (4) provide specific recommendations appropriate to the Department of Defense and others designed to address the need, (5) state the consequences to our long-term national security."
This report is a response to that request.

The science and technology (S&T) base has, as its cornerstone, basic research which, in the U.S., tends to be concentrated at universities. Approximately two-thirds of basic research in science and engineering (S&E) is carried out in academia. There is a concomitant integration of basic research with graduate education. The nation reaps a double benefit from this model in that it concurrently generates both research results and future researchers. It is for this reason that the state of U. S. university laboratory facilities is so important to the nation's long-range economic and military competitiveness.

The evolution of science and technology tends to create a requirement for more sophisticated research facilities. Failure to keep pace with facilities' needs has a negative impact on researchers' creativity. This in turn limits the scope of scientific endeavor in the experimental disciplines. The consequences may include delays in the realization of new discoveries and a trend for faculty and graduate students to opt for theoretical studies rather than engage in experimental research with inadequate facilities. A further consequence is the difficulty of recruiting and retaining the most productive faculty in experimental disciplines.

The foregoing points work against university researchers undertaking experimental investigations. When researchers do so in spite of inadequate facilities, results of their endeavors can be compromised in a variety of ways. These include:

- Inadequate environmental control resulting in decreased quality of data

- Excessive down-time resulting in diminished productivity

- Outmoded equipment leading to imprecision in acquired data

- Crowded laboratory space resulting in diminished access to equipment for data gathering and maintenance purposes

- Contrived experimental set-ups representing safety hazards

B. DEFINITIONS

The following definitions will be used throughout this report:

Laboratory Needs-Facilities and equipment which collectively constitute vehicles for the generation of experimental data and other information. It denotes more than a stand-alone instrument (e.g., spectrometer, tensile tester, etc.) that can be operated in general laboratory space typically found on a university campus, but excludes general purpose laboratory buildings. Examples include wind tunnels, high voltage accelerator labs, clean rooms, wave tanks, etc., especially those housed within existing older buildings. It may also include specially designed structures required to house laboratory instrumentation and experimental facilities.

Facilities-Laboratory structural environment including hardware required to maintain special conditions in laboratory space.

Equipment-Instrumentation and devices directly supportive of data acquisition and analysis.

C. RESEARCH DISCIPLINES AND THRUST AREAS

Selected research laboratory needs among universities active in Department of Defense (DOD) competitive research programs are addressed in this report for the following five disciplines and constituent thrust areas:

CHEMISTRY
- Laser Chemistry
- Polymeric Materials

ELECTRONICS
- Microelectronic Fabrication and Reliability
- System Robustness and Survivability

ENGINEERING
- Combustion
- Composite Structures
- Energetic Materials
- Fluid Mechanics and Acoustics
- Manufacturing, Design, and Reliability
- Soil Mechanics

MATERIALS
- Optical and Magnetic Materials
- Silicon and Compound Semiconductor Growth
- Structural Ceramics
- Structural Composites

PHYSICS
- Astrophysics
- Coherent Radiation Sources
- Directed Energy Devices
- Optical Communications and Spectroscopy

The foregoing disciplines do not represent the breadth of DOD research. In particular, biological and biomedical sciences are not included in anticipation of a comprehensive survey of laboratory needs by the National Institutes of Health. Computer resources not dedicated to experimental research facilities are also excluded on the basis that they are the object of considerable study and/or aggressive enhancement programs by the National Science Foundation and the Department of Energy.

D. INFORMATION ACQUISITION

Requisite information was initially assembled by research administrators in the three Service research offices (OXRs): the Office of Naval Research (ONR), Army Research Office (ARO), and the Air Force Office of Scientific Research (AFOSR) and in the Defense Advanced Research Projects Agency (DARPA). In particular, Division Directors in each organization representing the foregoing five research disciplines supplied data related to the sufficiency of research laboratory facilities. This information was analyzed for the purpose of developing laboratory needs representative of defense research priorities. Results are presented in Chapter IV in the form of prioritized laboratory needs (where they exist), estimated costs of desired enhancements, and assessments of the scientific/technological and national security implications of any laboratory needs identified.

Within the framework of the foregoing information acquisition plan, each of the three OXRs identified key R&D performers for the various research disciplines. These performers were then analyzed with reference to the indicated questions. Criteria used in determining the performers to be interrogated and/or analyzed for inclusion in the report involved level of basic (6.1) competitive research funding, evaluations by OXR research administrators, and, as appropriate, independent evaluations of graduate programs corresponding to the various disciplines. In many cases, the stated costs represent partial funding reflecting the tendency of universities to seek multiple sponsors for major laboratory improvements. While the method of data collection does not embody the statistical integrity of a rigorously implemented survey instrument, it is nonetheless thought to be suggestive of the dimensions of university laboratory needs of greatest importance to DOD. Further, the study differs from previous ones in that the cited laboratory needs reflect, in part, the judgment of research sponsors (DOD scientific officers) rather than exclusively the perceptions of research performers.

The primary DOD research performers encompassed by this report are, of course, only a subset of the total university R&D community. The extent to which their modernization and new facilities needs may be extrapolated to all universities performing research for DOD, or to the entire population of approximately 300 research universities in the U.S., is an open issue. Such extrapolations beg the question, however, as to appropriate means for assessing laboratory sufficiency from the DOD perspective. This is a complex question that is under constant scrutiny for each discipline and its constituent research areas. More generally, it is an issue which demands continued vigilance at the national level. Sustained deficiencies in any discipline/thrust area will inevitably cause the corresponding sector of the U.S. science and technology base to erode, thus blunting our competitive position in the national security and world economic arenas.

CHAPTER II
DOD SUPPORT FOR UNIVERSITY LABORATORIES

A. INTRODUCTION

This chapter deals with the role that universities play in sustaining and strengthening the U.S. science and technology base (Section A), the origins of DOD support of university laboratories in that role (Section B), DOD programs that support university science laboratories (Section C.1), and further steps that DOD has taken to upgrade these facilities (Section C.2). A new university research initiative for FY 86 (Section C.3) and coordination activities relevant to the upgrading of university research facilities are described (Section C.4).

Given the importance of university science laboratories to DOD, it is also true that maintaining adequate university research facilities is a national priority that has important economic as well as military significance. Thus, DOD should not and cannot solve the problem alone. Solutions must encompass all relevant government agencies, private industry, and, of course, the universities themselves. This chapter focuses, however, on the relationship between DOD and the university community.

American universities play an indispensable role in maintaining and strengthening the nation's science and technology base. Not only are universities the source of future scientists and engineers, but the research contributions of academia to society are vast as well. Since World War II, universities have performed most of the basic research that has produced the technological innovations on which much of our economy and national defense are based today. Universities contribute nearly three-quarters of the scholarly papers published in the most noted science and technology journals. In addition to generating the insight and knowledge upon which future technological innovation is based, university research provides the environment for the development of future scientists and engineers. The result is enrichment of the professional experience of faculty and graduate students involved in training our nation's technical manpower. Thus, support of university research produces multiple benefits of enormous value to society as a whole.

This report addresses selected needs of university laboratories involved in DOD sponsored research. As much as $2 billion has been estimated as the total sum needed to replace obsolete university research instrumentation. Laboratory facilities, including the instrumentation required to conduct research aimed at modernizing and expanding the U.S. technology base, are becoming increasingly expensive. Establishing and maintaining such facilities are very costly, especially those requiring advanced supercomputers, large particle accelerators, various types of analytical instrumentation, imaging devices, and automated design and manufacturing hardware. Nonetheless, such equipment is crucial for the conduct of research in important areas of science and engineering, and for educating students. DOD support for university research equipment is described in the following sections.

B. ORIGINS OF DOD SUPPORT FOR UNIVERSITY LABORATORIES

The DOD has recognized that technological superiority is essential to military superiority, and it has played an important role in maintaining the strength of the U.S. science and technology base. Since DOD was among the first federal agencies to recognize the essential role that the academic community plays in the maintenance of U.S. technological leadership, it has maintained a strong relationship with U.S. universities since before World War II.

Very little involvement of universities with military technology occurred during World War I, despite the existence of in-house Service laboratories since the 1890s and the earlier creation of the National Academy of Sciences, which was established as a war measure by President Lincoln in 1863. The sudden expansion of experimental and laboratory operations that characterized the outbreak of World War II greatly overburdened the Service laboratories. Many civilian scientists and engineers were added to the staffs of Aberdeen Proving Grounds, the Naval Research Laboratory, the Naval Ordinance Laboratory, Taylor Model Basin, Wright Field (Army Air Force), and Fort Monmouth (Signal Corps). Contracting funds were also greatly increased in the effort to catch up to an enemy that had scientific groups investigating improved weaponry since the early 1920s.

The Office of Scientific Research and Development (OSRD) was created, reporting directly to President Roosevelt, and receiving funds by direct appropriation from the Congress. These funds were placed in private and governmental laboratories. The National Research Council of the National Academy of Sciences had been created during World War I and was, by the time of World War II, well known to the military Services, which expanded their use of it. These arrangements formed a close coupling of the organized bodies of scientists and military leaders having a common appreciation of the importance of science and engineering to modern warfare. Major wartime expansion of facilities occurred at several universities. The major contributors included MIT, Harvard, Columbia, the University of Chicago, the University of California, the Johns Hopkins University, and the California Institute of Technology. Radar, acoustics, operations research, navigation, and atomic weapons were just a few of the areas in which notable contributions were made.

Emerging from the wartime era were two lasting methodologies for defense investment in university laboratory facilities. First, the institute concept became well established, wherein non-profit university affiliated laboratories conduct applied research, primarily under DOD support. Products of this era which make major contributions today are Lincoln Laboratories (MIT), the Johns Hopkins University Applied Physics Laboratory, the Applied Physics Laboratory of the University of Washington, the Applied Research Laboratories of the University of Texas, the Applied Research Laboratory of Pennsylvania State University, and the Marine Physical Laboratory, Scripps Institute of Oceanography, University of California, San Diego. Second, the National Security Act of 1947, and the amendment of 1948 which established the three military Departments and the Office of the Secretary of Defense, provided the framework that operates today for support of research at universities through the Army Research Office, the Office of Naval Research, the Air Force Office of

Scientific Research, and the Defense Advanced Research Projects Agency. This partnership has been substantial over the years; seventeen institutions of higher education are among the 595 contractors that received awards of 10 million dollars or more from DOD in FY 83.

C. PRESENT DOD SUPPORT FOR UNIVERSITY LABORATORIES

C.1 DIRECT FUNDING OF UNIVERSITY RESEARCH

U.S. universities are a major factor in current DOD activities affecting the U.S. technology base. Approximately half of all DOD basic research (6.1) funds are expended at universities ($405 million in contract dollars with research budgets totaling $840 million in FY 84), plus a smaller amount of applied research (6.2) funds (approximately $115 million in FY 84). During the past decade, DOD has made a major effort to reverse the effects of the relative neglect of university research that occurred during the Vietnam war. Figure II-1 shows the evolution of DOD funding for basic research (6.1) since 1962. The corresponding funding history for "exploratory development" (6.2), some of which equates to applied research, is shown in Figure II-2.

These figures show that funding in current dollars for both components of the technology base grew significantly during the late 1970s and early 1980s; nevertheless, neither has returned to 1965 levels of support in constant dollars. In fact, in real terms, the level of funding for exploratory development has been virtually stable for over a decade. In a memorandum to the Services dated August 9, 1984, Secretary Weinberger noted this situation and indicated that the Defense Guidance for the FY 1987-91 POM would request 8 percent annual real growth in both components of the technology base. DOD still takes that position.

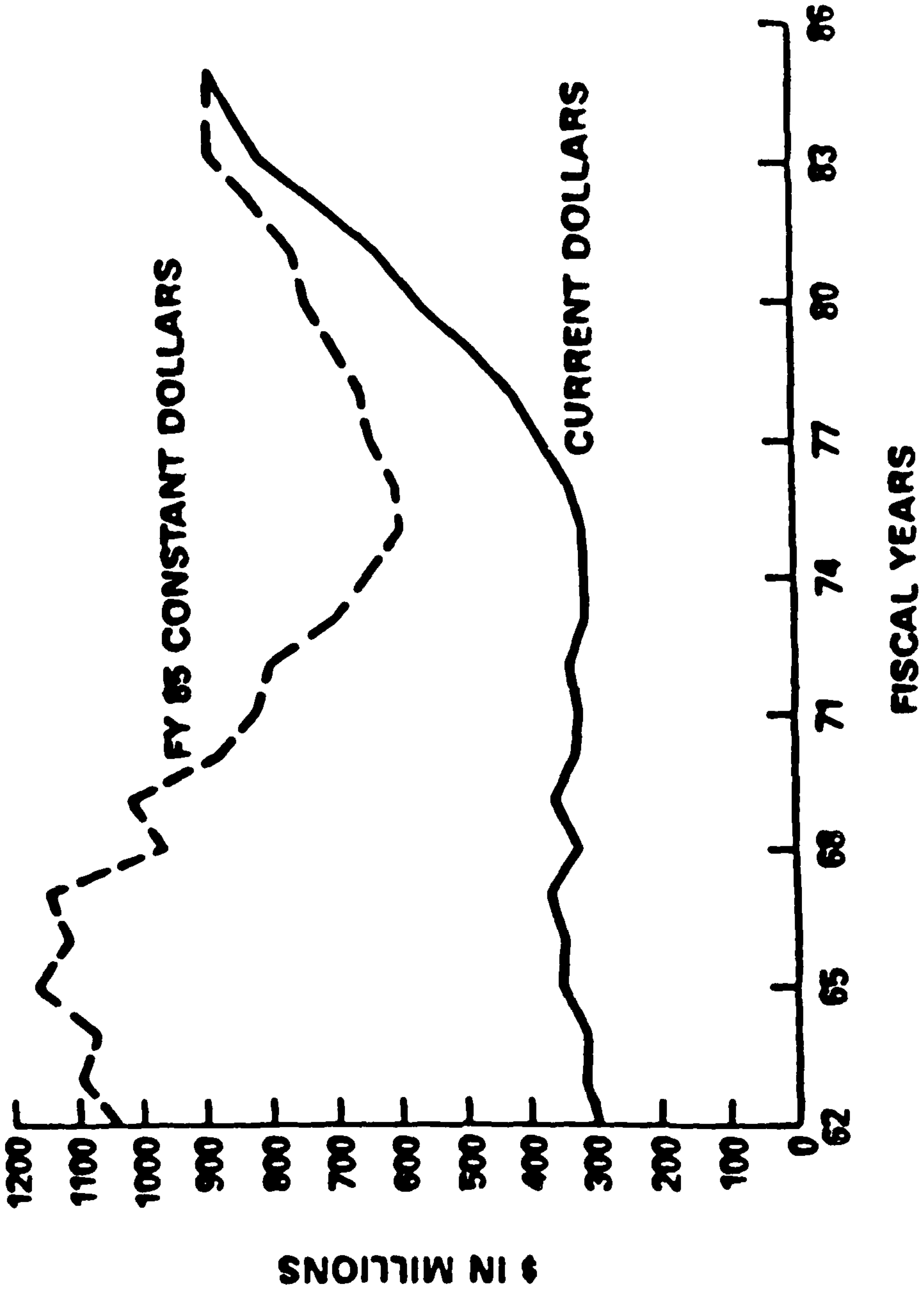
University research has been a major component of the growth in DOD technology base activities during the past decade. Table II-1 shows DOD Basic Research (6.1) funds spent (or projected to be spent) at universities by the Army, Navy, Air Force, and the Defense Advanced Research Projects Agency (DARPA) for the years FY 74-86. During the period FY 75 to FY 84, DOD spending for 6.1 Basic Research at universities grew at a real annual rate of 9 percent--far higher than the annual growth of DOD Research (6.1) funds as a whole.

Table II-1 shows only the DOD Basic Research (6.1) funds going to universities. It includes only contracts exceeding $25,000, and does not reflect research grants. Thus total university funding is somewhat higher than indicated. A similar break-out of the university component of DOD Exploratory Development (6.2) funds is not available. To provide a basis for comparing 6.1 and 6.2 expenditures, in FY 83 a total of $102.3 million in DOD Exploratory Development (6.2) contracts went to universities while $360 million was provided for Research (6.1) contracts. An additional $50 million was awarded to universities in the form of 6.1 research grants. DOD funding for universities is not limited to Research and Exploratory Development. For example, DOD RDT&E (6.1 through 6.6) contracts over $25,000 going to educational institutions in FY 83 totaled $1113.6 million. Most of the $600 million in the higher categories (6.3, 6.4, 6.5, and 6.6) was for R&D in university affiliated off-campus laboratories and Federally Funded Research and Development Centers (FFRDCs), or for vocational and technical training, and tuition fees.

FIGURE II-1

DOD SCIENCE AND TECHNOLOGY FUNDING TRENDS

CURRENT AND CONSTANT DOLLARS RESEARCH (6.1)

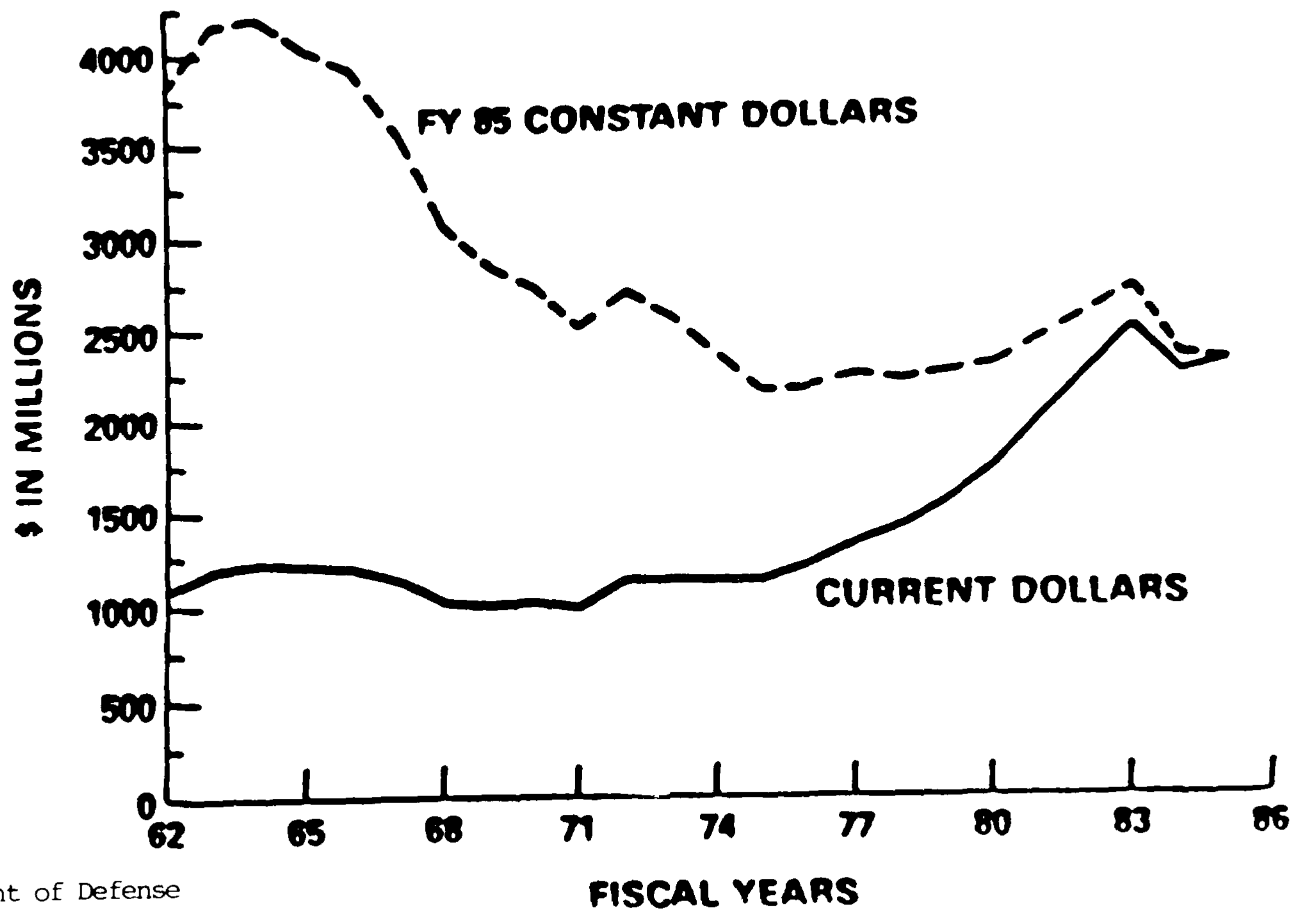


SOURCE: Department of Defense

FIGURE II-2

DOD SCIENCE AND TECHNOLOGY FUNDING TRENDS

CURRENT AND CONSTANT DOLLARS
EXPLORATORY DEVELOPMENT (6.2)



SOURCE: Department of Defense

CHAPTER IV

SELECTIVE UNIVERSITY LABORATORY MODERNIZATION

A. INTRODUCTION

This chapter addresses selected laboratory needs, i.e. facilities and related equipment, for a segment of the research university community representing key performers of DOD research for the disciplines and thrust areas enumerated in Chapter I. These needs, stratified by discipline and priority in Table IV-1, reflect the judgment of university research performers and, in certain cases, of administrators in the Service research offices (OXRs) and the Defense Advanced Research Projects Agency (DARPA). It should be emphasized that the cost figures in Table IV-1 are estimates of university laboratory upgrade and modernization initiatives designed to bring university laboratories closer to sufficiency from the DOD perspective. As previously indicated, they represent in many cases only partial funding of the facilities in question through multiple sponsor arrangements. They are not intended to encompass laboratory needs of the entire university research community. The latter issue has been addressed in the various studies cited in Chapter III. Facilities costs vary among and within disciplines, reflecting special requirements for the various thrust areas. They encompass both floor space requirements and laboratory accessories not falling within the instrumentation category. Thus, not all expenditures classified as "facilities" represent requirements for new or renovated buildings. The stated new floor space requirements are expressed in "gross" (as opposed to "net") square feet at $120/ft^2$. Laboratory renovation costs are calculated at $90/ft^2$.

The allocation of laboratory needs among the five disciplines required the exercise of judgment as to the appropriate division between (a) the parent, pure science fields of Physics and Chemistry, and (b) the applications-focused areas of Electronics, Engineering, and Materials. Ultimately, such decisions are to an extent arbitrary. Further, there are clearly a great number of ways to stratify facilities and equipment needs in terms of disciplines and thrust areas. The scheme presented in this report is thus only one of many possible approaches.

Priority 1 facilities needs for the five subject disciplines, pro-rated over a five-year expenditure period, are $32 million per year. The expenditure level is equivalent to the URIP annual allocation of $30 million. It is also of interest to note that priority 1 equipment requirements are $31 million per year, i.e., almost identical to the annual expenditure rate of the five-year $150 million URIP initiative. Unquestionably, some portion of the $155 million Priority 1 equipment needs cited in this report will be addressed during the final two years ($60 million) of the URIP program.

TABLE III-5

Number and aggregate cost/value of academic research instrument systems in active research use, by field and type of university: National estimates, 1982.[1]

[Dollars in millions]

Principal field of research use and type of university	Number of systems	Index of aggregate cost/value: Purchase cost[2]	Acquisition cost[3]	Replacement value[4]	1982 cost-equivalent[5]
Total, selected fields	17,586	$758.1	$703.2	$1,133.7	$1,162.8
Field of research					
Physical sciences, total	8,424	373.6	353.2	529.3	610.2
Chemistry	4,791	210.4	201.1	295.0	331.7
Physics and astronomy	3,633	163.2	152.1	234.3	278.4
Engineering, total	6,829	259.4	232.4	413.3	374.6
Electrical	1,650	66.4	56.0	92.2	89.0
Mechanical	1,363	50.9	47.8	95.5	66.9
Metallurgical/materials	998	39.0	36.6	65.2	60.9
Chemical	682	23.3	22.8	28.6	32.3
Civil	397	14.1	13.9	22.4	21.6
Other, n.e.c.	1,739	65.7	55.3	109.0	104.0

[1] Statistical estimates refer to research instrument systems (including all dedicated accessories and components) originally costing $10,000-$1,000,000 in physical science, engineering, and computer science departments and facilities at the 157 largest R&D colleges and universities in the U.S. Estimates limited to systems used for research in 1982. Sample size = 2,582 systems. The columns below do not add up to the indicated total because computer science, materials science, and interdisciplinary have been omitted from this abbreviated version of the original table.

[2] Manufacturer's list price at time of original purchase.

[3] Actual cost to acquire instrument system at this university, including transportation and construction/labor costs.

[4] User estimate of 1982 cost of same or functionally equivalent equipment.

[5] Original purchase cost converted to 1982 dollars using Machinery and Equipment Index of the Bureau of Labor Statistics' Annual Producer Price Index to adjust for inflation.

Source: "Academic Research Equipment in the Physical and Computer Sciences and Engineering"; National Science Foundation, December, 1984.

TABLE III-4

Instrumentation-related expenditures in academic departments and facilities, by field and type of university: National estimates, FY 1982[1]

[Dollars in millions]

Principal field of research in department/facility and type of university	FY 1982 expenditures: Total	Purchase of research equipment[2]	Purchase of research-related computer services[3]	Maintenance/ repair of research equipment[4]
Total, selected fields	$375.6	$231.0	$84.7	$60.0
Field of research				
Physical sciences, total	156.6	94.5	33.9	28.2
Chemistry	73.7	39.6	23.3	10.8
Physics and astronomy	83.7	55.2	10.9	17.6
Engineering, total	154.4	90.9	43.9	19.6
Electrical	52.9	36.2	11.5	5.2
Mechanical	23.0	8.7	10.8	3.5
Metallurgical/materials	9.4	7.4	0.8	1.2
Chemical	15.8	7.8	5.7	2.3
Civil	16.4	9.6	5.4	1.4
Other, n.e.c.	36.7	21.3	9.5	5.9

[1] Statistical estimates encompass all research departments and all nondepartmental research facilities in the physical sciences, engineering and computer science at the 157 largest R&D universities in the U.S., except: (a) departments with no research instrument systems costing $10,000 or more and (b) research installations consisting of interrelated components costing over $1 million (large observatories, reactors, accelerators, etc.). Sample size = 353 departments facilities. The columns below do not add up to the indicated totals because computer science and interdisciplinary have been omitted from this abbreviated version of the original table.

[2] Estimates refer to expenditures for nonexpendable, tangible property or software having a useful life of more than two years and an acquisition cost of $500 or more, used wholly or in part for scientific research.

[3] Estimates refer to purchase of computer services at on-campus and off-campus facilities but not to purchase of computer hardware or software.

[4] Estimates encompass expenditures for service contracts, field service, salaries of maintenance/repair personnel, and other direct costs of supplies, equipment and facilities for servicing of research instruments.

Source: "Academic Research Equipment in the Physical and Computer Sciences and Engineering"; National Science Foundation, December, 1984.

TABLE III-3

Annual Expenditures for Research Equipment
at Colleges and Universities
(thousands of dollars)

FIELD	1982	1983
Engineering	65,861	75,171
Aero/Astro	2,284	2,837
Chemical	6,442	6,172
Civil	5,164	6,086
Electrical	18,454	20,685
Mechanical	7,390	10,008
Other	26,127	29,383
Chemistry	33,323	32,826
Physics and Astronomy	38,316	39,916
Totals:	111,373	118,530

Source: National Science Foundation

Research equipment expenditures for U.S. colleges and universities are summarized in Table III-3 for 1982 and 1983. The data were obtained from 85 percent of U.S. universities in response to an NSF questionnaire concerning non-capitalized equipment expenditures. Engineering equipment purchases averaged approximately $70 million for the two year period. The category compares roughly to the combined engineering, electronics, and materials categories of this report.

Table III-4 lists 1982 estimated research equipment expenditures for 157 of the largest research universities. These 157 institutions collectively accounted for 95 percent of all nonmedical, non-FFRDC R&D expenditures reported to NSF for FY 1980 by all U.S. colleges and universities. Thus, although the survey represented only a small fraction of the nation's approximately 3,000 post-secondary institutions, it encompassed most institutions with significant capabilities for the kinds of advanced research that require instrumentation in the $10,000+ range. The quoted figures are somewhat higher than those in Table III-3, since they include capitalized equipment, whereas the data of Table III-3 do not. As in Table III-3, the engineering category compares roughly to the combined engineering, electronics, and materials categories of this report.

Acquisition and replacement costs as of 1982 for research equipment in the physical sciences and engineering are given in Table III-5. The total replacement value in 1982 dollars for both fields exceeded $1 billion. It is interesting to note that equipment maintenance in both the physical sciences and engineering represented 5 percent of replacement costs.

TABLE III-2

Research and Instructional Capital Expenditures at Colleges and Universities*

(thousands of dollars)

FIELD	1976	1977	1979	1980	1981	1982	1983
Engineering	81,678	87,718	87,128	89,297	103,329	144,990	134,701
Physical Sciences	73,755	65,216	64,685	77,154	87,813	82,362	87,073
Total:	155,433	152,934	151,813	166,451	191,142	227,352	221,774

Source: National Science Foundation

* 1978 Data not available.

For the purposes of this report, the Flad study has some interesting implications. If the study's findings are extrapolated onto the entire sample, total national private industry projected capital spending for research and development would be about $20 billion for 1983-85 (about $11 billion for plant and about $9.2 billion for equipment). This compares with estimates of $1 billion for total average annual planned investments in university science and education facilities. For industrial laboratories whose annual research and development budgets were in the range of 1 to 15 million dollars (45 percent of the responding firms), the expenditure planned for was about 13 percent of their annual operating budget each year for the three years beginning in 1983. The ratio of planned expenditures for equipment and plant by private industry was about the same (unity) as that shown for universities in Chapter IV below.

-- The NSF published a study of "Academic Research Equipment in the Physical and Computer Sciences and Engineering" in December 1984. This study surveyed 43 universities; respondents exhibited serious concern about the adequacy of their current stock of research equipment. Among the findings of the study were:

- About half of the department heads in physical and computer sciences and engineering characterized research instrumentation available to untenured and tenured faculty as "insufficient."

- 90 percent of the department heads surveyed reported that, as a result of lack of needed equipment, their research personnel could not conduct critical experiments in important subject areas.

- The top priority need was to upgrade and expand research equipment in the $10,000 to $1,000,000 range.

- The estimated original purchase cost of the entire 1982 stock of all $10,000 to $1,000,000 academic research equipment that had been accumulated in the fields surveyed was about $1 billion.

- Only 16 percent of those systems were classified as state-of-the-art. Of the equipment that was not in the state-of-the-art category, over half was in less than excellent condition; about half of such equipment was the most advanced to which researchers had access.

In addition to the studies and data surveyed above, the NSF has released a variety of data that are of special interest for this report. Table III-2 gives seven-year trend data on capital expenditures at all U.S. universities for both research and instructional purposes. Unfortunately, there does not appear to be any systematic way of extracting purely research facility expenditures from these figures. The two research categories cited correspond roughly to the five disciplines addressed in this report.

Table III-1

Actual and Projected Expenditures for Research Facilities
(new construction/renovation) and Special Research Equipment
for 15 Major Research Universities
(thousands of dollars)

FIELD	FACILITIES 1978-80	FACILITIES 1981	FACILITIES PROJECTED NEEDS 1982-84	SPECIAL RESEARCH EQUIPMENT 1978-80	SPECIAL RESEARCH EQUIPMENT 1981	SPECIAL RESEARCH EQUIPMENT PROJECTED NEEDS 1982-84
Chemical Sciences	13,835	14,089	115,022	6,701	4,767	14,688
Engineering	19,539	18,476	183,106	16,101	10,957	33,222
Physics	11,700	5,818	74,725	4,603	1,092	22,590

Source: "The Nation's Deteriorating University Research Facilities", Association of American Universities, 1981

these universities expected to spend almost twice as much ($765 million), just to produce the necessary research facilities and special research equipment for current faculty only.

- New construction to replace outmoded facilities accounted for almost 60 percent of total projected funding requirements across all fields.

- In addition, substantial needs for major research equipment were identified in all six fields.

Table III-1 shows the expenditures and projected needs for those disciplines included in the present report. Projected needs for both facilities and equipment were far larger (by factors ranging from three to almost ten) than actual expenditures for an equivalent period immediately preceding the report. The extent to which these differences represented realistic assessments of the pent-up facilities demand, and/or an effort on the part of survey respondents to "make a statement," is open to question.

Among the recommendations of the AAU study was:

- Provided that a review by key government agencies corroborated the assessment of the survey, the "Department of Defense, Department of Energy, the National Aeronautics and Space Administration, the Department of Health and Human Services, and the Department of Agriculture should establish research instrumentation and facilities rehabilitation programs targeted on the fields of science and engineering of primary significance to their missions."

-- In 1982, Flad & Associates, a Wisconsin architectural and planning firm, published their "Capital Spending Study of Research and Development Laboratories." Since the study focused exclusively on the spending plans of private industrial firms, it provides a useful basis for comparison with the plans of universities dealt with in the AAU studies described above.

The Flad study was based on a survey of some 5800 directors of industrial research laboratories. About twelve percent of them responded with detailed, confidential estimates of planned spending for plant and equipment in the ensuing three years (1983-85). The firms surveyed were considered more representative of large research laboratories (25-100 staff) than smaller laboratories (less than 25).

Among the major findings of the Flad study were:

- Estimated spending on research and development plant for 1983-85 by responding firms was $1.4 billion.

- Estimated spending on research and development equipment for 1983-85 was $1.2 billion.

- Nearly 40 percent of the laboratories of responding firms were built less than ten years before the survey; of these, 50 percent had undergone additions or renovations subsequent to initial construction.

CHAPTER III

PREVIOUS STUDIES

More than a dozen studies of university laboratory facilities have been prepared since the late 1960s. For a comprehensive listing and summary of such studies prepared by Linda S. Wilson of the University of Illinois at Urbana-Champaign, see the Appendix. Many of these studies have concluded that a problem exists with respect to inadequate and deteriorating university laboratory research facilities. Some of the studies are qualitative and generally recommend programs for the support of facilities renewal. Others are quantitative and are based on surveys of the conditions of facilities, with projections of the amount and cost of construction and renovation required to meet future needs. The basic conclusion drawn is that renewal and replacement of facilities are an important element in assuring a national technology base. Some of the more relevant studies for the purposes of this report are discussed below. An analysis of some of their findings in comparison to the present study is given in Chapter V.

-- A report to the National Science Foundation (NSF) by the Association of American Universities (AAU) in June, 1980, was devoted to "The Scientific Instrumentation Needs of Research Universities." Numerical data for the study were gathered from 14 universities and four commercial laboratories. The report found that the median age of university equipment was twice that of the commercial laboratories' instrumentation. Concluding that "the quality of research instrumentation in major university laboratories" has seriously eroded, the AAU report recommended that:

> "Federal policy for the support of research instrumentation should provide for a basic three-part funding strategy:
>
> o Strengthen instrumentation funding in the project system.
>
> o Expand special instrumentation programs.
>
> o Create in the National Science Foundation a new, supplemental formula grant program to provide needed flexibility to meet diverse institutional needs."

-- A 1981 study prepared for the Committee on Science and Research of the AAU, entitled "The Nation's Deteriorating University Research Facilities," was based on a survey of recent expenditures and projected needs of fifteen major U.S. universities in six disciplines. The principal findings of the study were:

o A substantial backlog of research facilities and equipment needs was accumulating.

o During the 1978-81 period, for the six fields surveyed, the fifteen universities spent $400 million for facilities and major equipment. In the next three years (1982-84),

In FY 84, in addition to the $30 million per year of special URIP purchases, the three Services and DARPA purchased over $45 million worth of research instruments and equipment for universities in connection with their research contracting activities.

C.3 UNIVERSITY RESEARCH INITIATIVE

In FY 86, DOD plans to establish new research program elements that will be focused exclusively on the DOD/university relationship. Total proposed funding for the new program elements is $25 million in FY 86 and $50 million in FY 87. Significant additional growth is expected after FY 87. Each of the Services and DARPA will implement programs within these program elements to meet the priorities of their own relationships with the academic community. Although the specific proportions will vary from Service to Service, graduate fellowships, support for young investigators, purchase of research instrumentation, support of special research programs, and programs to improve the interactions between DOD laboratory and university researchers, will be part of the total DOD package.

C.4 COORDINATION ACTIVITIES

DOD has long recognized that the academic community is an invaluable source of expert advice. The Department draws on science and engineering faculty as individual consultants and as members of DOD advisory committees. To insure more effective communication with the academic community, DOD established the DOD/University Forum in December 1983. During its first year, the Forum has provided a mechanism for dialogue between DOD and the academic community on policy and other issues of mutual interest. One significant outcome of its activities during the past year was the establishment of a new DOD policy on the transfer of scientific information. It establishes an appropriate balance between the conflicting imperatives of national security and open scientific communications. The Forum Working Group on Science and Engineering Education addressed many issues, including that of research instrumentation.

URIP provides $150 million over five years for university research equipment. Each of the three Services is programmed to spend $10 million per year. So far, $90 million has been spent on 652 awards going to 152 institutions in 47 states and Washington, D.C., Guam, and Puerto Rico. While URIP is having a major impact on the equipment needs of researchers doing work of interest to DOD, it cannot solve the whole university instrumentation problem. In the first year of URIP, DOD received 2,500 proposals representing requests for $646 million worth of equipment. While some of these requests were for equipment to support research in areas not usually funded by DOD, this response is a significant and impressive measure of the needs of the universities.

URIP is the most visible, but not the sole, DOD response to the university instrumentation problem. As noted previously, each of the Services and DARPA have encouraged current and prospective contractors to make their equipment needs known, in order that many of the less expensive items could be purchased as an integral part of research program funding:

- Approximately 10 percent of Army, Navy, and Air Force research contract funding is applied to equipment purchases, most of it well under $50,000. Grants under the URIP program provide an additional comparable dollar amount for equipment costing more than $50,000.

- The portion of the Army Research Office (ARO) contract program devoted to instrument purchases has increased steadily over the past decade; in FY 85, such purchases will represent about $6 million of the ARO contract research program.

- University-related equipment purchases associated with the Contract Research Program of the Office of Naval Research (ONR) increased from $11.2 million in 1979 to $16.6 million in 1984.

- Between 1975 and 1985, vested equipment funding by the Air Force Office of Scientific Research (AFOSR), during the usual course of its sponsored research program, increased from $2 million to $8 million.

- Although DARPA does not participate in the URIP program, 10 to 20 percent of its university program funds have been utilized for equipment. In 1981, DARPA began a modernization program focused on obsolete equipment and the need for greater computational power. From 1981 to 1984, equipment purchases by universities using DARPA funds increased from $6.7 million to $16.8 million.

In certain cases where the equipment for major research efforts has been especially costly, provisions have been made for extraordinary purchases. Examples include the purchase of large main frame computers, semiconductor processing lines, molecular beam epitaxy and analysis chambers, and ARPANET computational and communication facilities by DARPA, and an ongoing ONR program to refurbish selected research vessels.

DOD sponsors research and development at universities to ensure the progress in fundamental knowledge that is necessary, in the long run, to maintain U.S. technological superiority. The resulting university research programs also serve to benefit universities in a variety of ways. By providing opportunities to perform basic research at the forefront of science and engineering, research programs at universities help to create an environment that can attract and retain faculty and students. Past studies suggest that, on average, $1 million of fundir for research provides full or partial financial support for 10-15 graduate students. Using this measure, DOD provided financial assistance for over 4000 graduate students through its university research programs in FY 84. In addition, as will be noted below, DOD-related research programs also have significant effects on laboratory instrumentation.

C.2 INSTRUMENTATION PROGRAM

Instrumentation is essential to modern research. Modern instruments with qualitatively superior capabilities for analysis and measurement often open new fields of scientific inquiry. In some scientific areas, access to the most advanced scientific instrumentation determines in large measure the extent to which scientists can work at the cutting edge of their field.

The Department of Defense, in concert with the scientific and university community, state and other federal agencies, and the Congress, perceived that the condition of research instrumentation in U.S. universities declined significantly during the 1970s. The Association of American Universities (AAU), in a report to the National Science Foundation (NSF) in June 1980 (see Chapter III), concluded that the equipment being used in the top ranked universities has a median age twice that of the instrumentation available to leading industrial research laboratories, an additional factor in the attraction of potential faculty to industry.

The instrumentation problem has been growing for more than a decade. It reflects both economic factors and funding patterns:

- The cost of equipment has risen much faster than inflation.

- The system of one to three year contracts in the $50,000 to $100,000 per year range with individual investigators is not conducive to obtaining equipment that costs more than $50,000.

- Rapid technological advances are rendering research equipment obsclete at an ever increasing rate.

In response to the foregoing situation, DOD has encouraged researchers to include more of their equipment needs in proposals and emphasized that DOD does not set arbitrary limits on the amount of money that may be requested for instrumentation. This approach has been helpful for equipment needs in the $50,000 range or less. However, new money was clearly needed for some of the more expensive items required to modernize university laboratories. These funds were provided in FY 83 through the DOD-University Research Instrumentation Program (URIP), which received Congressional approbation.

TABLE II-1

DEPARTMENT OF DEFENSE FUNDING FOR UNIVERSITY BASIC (6.1) CONTRACT RESEARCH, FISCAL YEARS 1974-85+

(In millions of dollars)

Service	FY 74 Current	FY 74 Real	FY 75 Current	FY 75 Real	FY 76 Current	FY 76 Real	FY 77 Current	FY 77 Real	FY 78 Current	FY 78 Real	FY 79 Current	FY 79 Real	FY 80 Current	FY 80 Real
ARMY	13.7	27.9	13.4	25.0	19.0	33.7	23.7	39.6	28.1	43.8	32.0	45.9	39.1	50.[illegible]
AIR FORCE	23.2	47.3	22.9	42.6	28.2	50.0	41.0	68.6	49.5	77.1	46.4	66.5	55.3	72.[illegible]
NAVY	45.5	92.7	47.0	89.2	64.2	113.8	62.7	104.8	70.8	110.3	86.4	124.0	109.2	131.[illegible]
DARPA	21.9	44.6	19.4	36.1	19.1	33.9	18.7	31.3	17.9	27.9	21.0	30.1	19.8	26.[illegible]
TOTAL	104.3	212.4	103.6	192.9	130.5	231.4	146.1	244.3	166.3	259.0	185.8	266.5	213.4	2[illegible].1

Service	FY 81 Current	FY 81 Real	FY 82 Current	FY 82 Real	FY 83 Current	FY 83 Real	FY 84 Current	FY 84 Real	FY 85* Current	FY 85* Real**	FY 86* Current	FY 86* Real**
ARMY	46.5	55.9	56.1	63.5	71.4	77.7	80.6	84.6	83.8	83.8	87.9	83.8
AIR FORCE	63.4	76.2	71.5	81.0	90.3	98.3	112.1	117.6	119.1	119.1	135.0	129.7
NAVY	115.0	138.2	142.3	161.2	152.2	165.6	158.1	165.9	176.1	176.1	198.8	189.5
DARPA	27.3	37.8	39.4	44.6	46.4	50.5	53.9	56.6	42.7	42.7	43.4	41.4
TOTAL	252.2	303.1	309.3	350.3	360.3	392.1	404.7	424.7	421.7+	421.7	459.1	437.7

* Projections

** Forecast for inflation is based on CBO projection

SOURCE: Army Deputy Chief of Staff Research Development and Acquisition, Office of Naval Research, Air Force Office of Scientific Research, Defense Advanced Research Projects Agency, (Constant 1985 Dollars Calculated using GNP Implicit Price Deflator)

+Restricted to awards exceeding $25,000; grants are not included

Table IV-1. Summary of selected laboratory needs of major university performers of defense research.

Discipline	Priority	Building Requirements (gross ft^2)	Cost ($ thousands)* Facilities	Equipment	Total Costs
Chemistry	1	35,000	5,000	14,000	19,000
	2	412,000	44,[illegible]00	33,400	78,100
Subtotals		447,000	49,700	47,400	97,100
Electronics	1	130,000	49,000	33,000	82,000
	2	25,000	6,000	8,000	14,000
Subtotals		155,000	55,000	41,000	96,000
Engineering	1	296,500	36,200	39,000	75,200
	2	45,300	8,900	18,300	27,200
Subtotals		341,800	45,100	57,300	102,400
Materials	1	220,000	55,000	62,100	117,100
	2	170,000	29,000	36,400	65,400
Subtotals		390,000	84,000	98,500	182,500
Physics	1	80,000	15,800	9,300	25,100
	2	131,000	25,700	163,300**	189,000**
Subtotals		211,000	41,500	172,600**	214,100**
Summary	1	761,500	161,000	157,400	318,400
	2	783,300	114,300	259,400**	373,700**
Totals		1,544,800	275,300	416,800**	692,100**

*Numbers are rounded to the nearest $100 thousand.

**Includes $150 million for astrophysics high angular resolution imager.

B. DISCIPLINES

B.1. Chemistry

Large facilities are playing an increasingly important role in chemical research. It has been an evolutionary process, starting with opportunities provided by large instrumentation and moving to facilities comprised of clusters of large integrated instrumentation/computational facilities in regional spectroscopic facilities.

Ultra high vacuum chambers with sophisticated analytical instrumentation using laser, electron, and ion cluster beams, together with various spectrometers, are mandatory for leading edge research in many areas of chemistry. Lasers have become important analytical tools to study the dynamics of chemical reactions and to photoinduce reactions. These instruments are usually short wavelength visible or ultraviolet tunable lasers that are themselves pushing the limits of laser technology and hence require considerable expertise and expense to operate and maintain. In addition, many research projects are concerned with the chemistry of materials processing, such as integrated circuit fabrication, that demand clean room facilities by their very nature.

In order to remain globally competitive, particularly in areas of chemistry of importance to DOD, it has been recently recognized that traditional chemical research laboratory facilities at universities are in serious need of upgrading and that shared centralized new facilities are necessary due to the high costs of the instrumentation and environmental control required. This evaluation applies to the two topical areas identified by DOD research managers as candidates for facilities upgrading, based on scientific opportunities and on laboratory needs. These priority topics are laser chemistry and polymeric materials.

Lasers have become a valuable tool in many branches of chemistry. Catalytic activity and selectivity can be studied by using laser Raman spectroscopy to determine the vibrational modes and polarization of structures of molecules adsorbed on single crystal surfaces. High powered photo-ionizing lasers can be used in conjunction with ion cyclotron resonance spectroscopy to study the role of metal ions as selective chemical ionization reagents. Laser induced fluorescence of metallic ions and subsequent transfer of energy to neutral ions may yield superior detection limits, compared to well established analytical techniques that employ fluorescence of neutral metal ions in flames. Two step laser photo dissociation of small molecules can be used to elucidate isotope separation and enrichment processes. In this latter process, an intense pulsed infrared laser vibrationally excites molecules containing the chosen atomic isotope and a second ultraviolet laser photodissociates the molecule, allowing the desired atomic isotope to be collected from the photo fragments. These examples indicate the utilitarian richness of lasers in modern chemistry and illustrate that often they are used in combination with other sophisticated analytical equipment. The facilities investment described here would establish fifteen laser chemistry centers

where the operation and maintenance of the lasers would be accomplished by support specialists to serve several research projects. On an even larger scale of centralization, a single free electron laser facility would also be established to provide a very intense and widely tunable source of radiation.

Polymeric materials are found in most military equipment, because of their excellent chemical stability, mechanical properties, and low cost. The majority of the research support for improvements in these materials comes from industry in pursuit of commercial applications, although DOD does support some research specific to stringent military requirements. However, the polymer research of greatest interest to DOD, and for which university facilities upgrades are needed, concerns conducting polymers and polymeric approaches to structural composites, ceramics, and self-reinforcing polymers. It is important to note that independent industrial support of research in these areas is minimal or not aimed at DOD needs.

Conducting polymers that would combine the processability, durability, and light weight of plastics with the electrical conductivity of metal would find a wide range of applications in military systems ranging from solar cells and batteries to integrated circuits and stealth structures. Polyacetylene was the first organic polymer to exhibit electrical conductivity that could range from that of glass to that of metal, depending on the amount of dopants introduced. Doping methods have expanded to include solution doping, ion implantation, and electrochemical doping. Other new polymers have been made conducting, including polypyrrole and polythiophene. Polymer processability and stability are degraded by the doping methods currently used to induce conductivity. Much research is directed at improved doping techniques and on incorporating conducting polymers into nonconducting polymer matrices, as well as fundamental studies to explain the mechanism of electroactivity.

Fiber reinforced composite structural materials are finding many engineering applications, some of which are described under Materials and Engineering. Examples of the Chemistry research topics include organometallic polymer precursors for producing the fibers and self-reinforced or ordered polymers to attain the mechanical properties of fiber-reinforced composites without the need for fiber reinforcement. The most notable of the self-reinforced polymers developed under DOD sponsorship is polybenzothiazole (PBT), which exhibits an extended rigid chain alignment at the ultra-structural level. It offers low-cost processing, by casting and extrusion, instead of the sequence of weaving fibers, stacking of many thin plys, and curing at high temperature required for conventional fiber-reinforced composites.

Other polymeric materials research includes biopolymers, such as the polysaccarides for reduced hydrodynamic drag and non-linear electro-optic polymers for optical signal processing applications. The facilities investment described here would provide the polymer processing and characterization facilities for several focused centers of university research on electrical, optical, magnetic, and structural polymers.

B.2 Electronics

In addition to the traditional subject areas of electronic devices, circuits, and systems, the Electronics research program of DOD encompasses elements of information processing, low energy laser physics, optics, and material growth. For the purposes of this study, the facilities required for the growth of electronic and optical materials are reported under Materials and the low energy lasers, optical circuits, and vacuum tube research facilities are reported under Physics. The information processing research, being closely related to computer science, is not discussed, since, as mentioned in the Introduction, the National Science Foundation (NSF) and the Department of Energy (DOE) have major facilities programs in progress to provide scientific supercomputing access to university researchers. DOD, through the modernization program of the Defense Advanced Research Projects Agency (DARPA), recently made a significant upgrade in university computing facilities for symbolic computing in anticipation of the thrust in strategic computing. The Office of Naval Research is making available to its principal investigators a significant portion of the time of the Naval Research Laboratories' supercomputer at no cost to the existing research contracts.

A strong and clear consensus has emerged from this study indicating that the research managers of the Electronics program within the DOD feel that microcircuit fabrication at dimensions much smaller than those of the Very High Speed Integrated Circuits (VHSIC) program represents the greatest opportunity and greatest research facility need within Electronics. The feature sizes desired are 10 to 100 times smaller than the one-micron regime currently being advanced under VHSIC. It is in this regime that entirely new modes of operation of electronic, optical, and magnetic devices occur, due to the quantum effects produced by the limited number of atoms contained within these small dimensions. These phenomena present the possibility of creating devices whose performance can be greatly superior to that predicted from the bulk characteristics of the material from which they are fabricated. This has already been observed for high speed field effect transistors (FETS), when the device dimensions are reduced below one-tenth micron. It has also been observed that dramatic increases in transmission properties of optical materials occur when very thin layers of material are stacked in a multilayer sequence, offering the possibility of improved photodetectors and lasers.

The fabrication of these novel devices requires very advanced and expensive equipment for the deposition, lithography, and selective removal of the deposited materials. In addition, sensitive analysis of the surfaces and interfaces between dissimilar materials needs to be performed during the fabrication process. This is in contrast to current commercial practice (even for sophisticated microcircuits), where the analysis by electron microscopes and spectrometers is accomplished after the circuits are removed from the fabrication apparatus and before they are inserted into the next apparatus in the fabrication sequence. This requirement for in-situ analysis has greatly increased the minimum cost of doing research on device fabrication.

The facilities in which this instrumentation is housed require extreme control over air purity, to avoid dust particle disruption of the fabrication, and extreme control over vibration, to avoid misalignment of

the successive patterns employed in the fabrication sequence. The reliability of these as yet undeveloped circuits is anticipated to be a major concern that is best addressed early in their development, since the failure phenomena are anticipated to be inextricably tied to the fabrication process employed at the microscopic level.

For these reasons, the first priority in microcircuit fabrication was given to the refurbishment and upgrading of up to six university centers for microcircuit fabrication, with a second priority of augmenting two university reliability research centers to work closely on this new class of circuits.

In a separate, but related, research area, reliability at the systems level is perceived to be threatened today by the susceptibility of advanced solid state circuits to electromagnetic interference at relatively modest power levels. Research into hardening weapons systems against intentional enemy electromagnetic interference or inadvertent disruption by radiation from nearby friendly systems is required. The facilities for enabling university participation in this research include anechoic chambers and electromagnetic measurement instrumentation as a first priority, and dedicated computational facilities for modeling as a second priority.

B.3. Engineering

Engineering encompasses the disciplines usually associated with university departments of mechanical engineering, aeronautics and astronautics, civil engineering, industrial engineering, and materials engineering. The subject matter frequently overlaps that of the other disciplines, such as Materials or Chemistry, but is usually closer to a specific end application or requirement. For example, composite structures is a thrust area that has the same ultimate goal as Materials research on structural composites, namely lighter weight and stronger structures for building weapons platforms. The distinction is the focus in Engineering on determining the performance of composites through innovative design and analysis of structures using state-of-the-art materials. Research results are fed back to materials scientists to provide guidance to their endeavors. A base of knowledge about optimal design methods is thereby developed for application to many problems. Proceeding with this example, non-destructive evaluation (NDE) techniques must be developed to enable the engineer to perform these measurements in support of the analysis of composite structures. There is considerable resultant interaction with the materials scientists who also need NDE techniques to evaluate their progress in controlling the composition of materials.

Similarly, the area of Energetic Materials and Combustion involves considerable interaction with chemists to improve propellants, explosives, and fuels. The facilities in these two areas are typically large and have a significant element of concern for the safety of the personnel performing the research. The instrumentation is becoming dominated by lasers and analytical tools similar to that needed in Materials science.

Fluid mechanics and acoustics are the classical, almost exclusive, domain of Engineering, with slight involvement by molecular and chemical

physics. The facilities are typified by dedicated wind tunnels and water tunnels. Instrumentation is dominated by automatic digital data acquisition and digital computer modeling and simulation of the phenomena. Laser probes and acoustic sensors with sophisticated signal processing are also mainstays of instrumentation in this discipline.

Manufacturing, design, and reliability have increasingly been moving toward a computer-dominated emphasis on graphics, design aids, expert systems for process control, artificial intelligence to relieve pilot workload in single seat helicopters, and self diagnosis and self repair of machines and weapons systems. Classical industrial engineering, computer science, and structural engineering are very much coming together in this field. The facilities are replicas of factory workcells or simulators of aircraft cockpits and the instrumentation is heavily computer networked. The Defense Advanced Research Projects Agency (DARPA) is making advanced teleconferencing equipment available to several university centers in robotics so they may test their algorithms for robot vision on the DARPA autonomous land vehicle located at a contractor facility. They will also plan to provide replicas of a fingered robot hand to many of these university research centers. Non-destructive evaluation for manufacturing process monitoring and control, as well as for inspection of finished parts and fielded systems, requires a comprehensive research program, which would best be accomplished through a center of excellence in non-destructive evaluation/characterization.

Soil mechanics is uniquely supportive of blast hardened silos, construction, maintenance, and repair of runways, and priority command, control, and communications centers. The facilities at universities are presses, shock tubes, or high-G centrifuges.

B. 4. Materials

Materials research includes the growth of semiconductor, magnetic, and optical materials, as well as processing and fabrication of structural materials such as metal alloys, ceramics, and composites. The processing of semiconductor materials into electronic and optical devices and circuits is reported under Electronics, while the testing of structural composite materials and non-destructive evaluation for both manufacturing and in-process control of materials is reported under Engineering. This traditional division of research responsibility has begun to blur in recent years, and multidisciplinary research teams have been forming in recognition of the strong interaction between material growth, component fabrication, and ultimate system performance. In fact, for optimum coordination, the facilities requirements reported in this section for compound semiconductor growth should be co-located or closely adjacent to the microelectronic fabrication and reliability facilities reported under Electronics.

The greatest potential payoff and also the greatest investment costs are perceived by DOD materials research managers to be associated with two areas: the growth of compound semiconductors and the fabrication of advanced structural composites. High priority at somewhat reduced investment is given to facilities for optical and magnetic materials and for research on structural ceramics.

Compound semiconductor growth has received only a small fraction of the scientific and technical attention that has been spent on silicon. This has been entirely justified to date, since silicon possesses excellent electrical, thermal, and chemical properties, especially with its high quality native oxides and silicides. Being an elemental semiconductor, silicon is significantly simpler from a device processing standpoint than the compound semiconductors, such as gallium arsenide, cadmium telluride, and alloys, e.g. gallium aluminum arsenide and mercury cadmium telluride. The steady doubling of the capability of silicon integrated circuits every two to four years for the past twenty years is evidence of the wisdom of this research investment strategy. It is only recently that the material property limitations of silicon have presented a serious limit to device performance. Research attention is currently turning to at least three ways to get around this limitation. One approach is mentioned in the Electronics section, having to do with new device physics associated with ultra small device dimensions. A second approach, for information processing, is to use artificial intelligence to make "smarter" rather than just "faster" computers. The third approach is to turn significant resources toward the growth and characterization of the compound semiconductors. The facilities investment that is detailed here would permit four to seven university centers to advance the technology of compound semiconductors for signal detection, signal processing, millimeter waves, and communications, to name just a few DOD priority applications.

Composites materials have similar exciting potential for structural applications, ranging from high strength, lightweight airframes and large space structures to lightweight armor for highly mobile combat vehicles. These materials utilize high strength fibers embedded in polymeric, metal, or ceramic matrices. The creation of the fiber itself and the interaction between the fiber and the matrix during the processing largely determine the performance and reliability of the composite when exposed to harsh military environments over its service life. Only recently have advances in analytical tools permitted the microscopic characterization of these materials, both physically and chemically. These tools are both elegant and expensive. The facilities investment detailed here would establish, through new construction and refurbishment, six centers of university research on structural composite materials.

Optical materials are beginning to emerge in communications and signal processing applications. The advances that have been made in optical waveguides using silica glass exemplify the success possible through materials processing research. The combined stringent requirements for low transmission loss and very high tensile strength were achieved through research linking materials structure, properties, and performance. Magnetic materials in bulk form are widely used in critical electrical components, such as electromechanical switches and microwave phased array transmitters and receivers. In thin film form, magnetic materials are used for recording media and non-volatile memory. The facilities investment described here would establish two university centers in optical materials and would augment one existing university center in magnetic materials.

Structural ceramics research of high quality is performed in a number of small university laboratories that are in need of refurbishment and expansion to apply modern microstructural analysis techniques to

processing of high temperature ceramics for hostile environments. Both bulk ceramic components, such as radomes for high velocity aircraft, and ceramic coatings on turbine engine components would benefit from this upgraded research capability.

Finally, it should be noted that a segment of the materials research community is dependent upon support from very large research facilities, such as synchrotron and neutron sources. None of these facilities are included in this report. The predominant funding for these national facilities comes from NSF and DOE, with only minor support from DOD. Any decrease in support of these facilities by the other agencies would severely affect the DOD Materials research program.

B.5. Physics

Research on new and improved sources of electromagnetic radiation is a major component of the Physics program of DOD. The free electron laser is a direct result of high risk research funded by DOD. It has demonstrated an entirely new mechanism for generating coherent radiation that is freed from the usual constraints imposed by the need for a material medium. This device has already demonstrated that very wide tunable bandwidth is possible; this has great implications for its utility as a scientific research tool in the analysis of materials, and as a frequency agile radiation source for potential military applications, such as communications and target tracking. Recirculating the electron beam in storage rings offers theoretically high efficiency and hence the potential of high power free electron lasers for directed energy weapons application. The facilities investment reported in this section under coherent radiation sources would refurbish and upgrade three to four existing laboratories performing research on these novel sources.

More conventional lasers for a variety of wavelengths are being explored as tools for research on ultra small integrated circuits, optical computing, catalysis, and molecular biology and for tactical warfare applications such as target designation, optical jamming, and covert communications. The first demonstration of the use of a finely focused laser beam to deposit micron-sized metal connecting lines on semiconductor surfaces occurred under DOD sponsorship in the last five years. It was immediately picked up by the integrated circuit manufacturers as a tool for repairing defects in expensive integrated circuits, and in the photomasks used to produce the circuits. Prior to this breakthrough, lasers had only been used to remove excess material from circuits by vaporizing short circuits and trimming resistors to tolerance. This research continues today under DOD sponsorship and is demonstrating novel methods of doping circuits and of depositing insulators and conductors.

Other laser research projects are attempting to leapfrog over the limitation foreseen in silicon integrated circuits that results from the fact that as much as three-quarters of the surface of these circuits is devoted to metal interconnecting lines between the hundreds of thousands of constituent transistors. The propagation delay of the signals moving on these interconnects at the speed of light is becoming more important in determining the circuit speed than is the switching speed of the transistors. Optical computing chips afford the prospect of distributing the signals by laser beams to many portions of the circuit simultaneously,

thereby avoiding the input-output bottleneck of electrical integrated circuits. The facilities reported under optical communications and spectroscopy in this section would establish a new center for optical circuitry and would upgrade an existing laboratory for optical communications.

Directed energy devices require large facilities for research. The high voltages and currents required can only be stored and switched by physically large components as dictated by the scaling laws of electrical power engineering. To some extent this represents a departure from the usual scale of university research funded by DOD, since "big physics" is usually supported by NSF or DOE. DOD has funded university centers in pulsed power, but this has represented only approximately 10 percent of the physics budget. The facilities described under directed energy devices would expand the existing pulsed power centers and upgrade other centers for research on accelerators and microwave and millimeterwave high power sources. Beam propagation and the interaction of electromagnetic energy with materials would also be studied at these centers.

Astrophysics research directly produces knowledge of the background radiation against which space objects must be detected. Secondarily, the advances in instrumentation (optics, infrared, and x-ray) needed to conduct this research improve our military capability to detect and track space objects and to detect nuclear events in space. The major facility upgrade in this section, and indeed, the single highest cost item in the entire report is a $150M high angular resolution imager center whose goal is a hundred-fold increase in image sharpness on celestial objects and space vehicles.

C. SUMMARIES

Laboratory facilities and equipment needs for thrust areas associated with the foregoing disciplines are given in the following summaries. The science and technology implications of laboratory enhancements, and their national security consequences are also addressed.

CHEMISTRY

Thrust Area: Laser Chemistry

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 --	
New construction	---	---
Renovation/expansion	20,000	3,000
	-- Priority 2 --	
New construction	75,000	9,000
Renovation/expansion	150,000	13,500
Subtotal	245,000	25,500

Equipment: Linear accelerator and storage ring electron sources; upgrade equipment for free electron laser facility to enhance short wave-length beam power; arrays of six lasers (dye, argon ion), with diagnostic, data processing, and beam direction equipment for each of 15 laser chemistry centers.

Priority	Cost ($ thousands)
1	7,000
2	30,000
Subtotal	37,000

Total Cost: $62,500,000

Technical Objectives and Opportunities:

-- Priority 1 --

An upgraded free electron laser laboratory would be established. It would be a high power, high time resolution facility essential to progress in chemical reaction kinetics, surface physics and chemistry, hot carrier electron transport investigations, and high resolution photo emission studies.

-- Priority 2 --

Fifteen laser chemistry centers would be established. This number represents a best estimate of university community requirements to ensure that DOD-sponsored research in the field is conducted in an efficient, cost-effective manner. Centralized laser resources would facilitate the sharing of expensive instrumentation and permit a reduction of maintenance costs through the pooling of technicians and shop facilities. The centers would include picosecond lasers which, especially in the ultraviolet region, offer a new tool for studying the dynamics of chemical reactions.

National Security Consequences: Fundamental knowledge of chemical reactions is crucial to much of military technology, e.g., to the improvement of propellants, explosives, fuels, lubricants, and high energy lasers.

CHEMISTRY

Thrust Area: Polymeric Materials

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 --	
New construction	---	---
Renovation/expansion	15,000	2,000
	-- Priority 2 --	
New construction	170,000	20,500
Renovation/expansion	17,000	1,700
Subtotals	202,000	24,200

Equipment: Polymer molding; film casting; film and fibers drawing/ orientation equipment; integrated scanning transmission electron microscopes and x-ray detector systems; SQUID magnetometers; picosecond spectroscopy systems; Fourier transform nuclear magnetic resonance units; electrophoresis equipment; data processing and analysis instrumentation; dedicated computer resources.

Priority	Cost ($ thousands)
1	7,000
2	3,350
Subtotal	10,350

Total Cost: $34,550,000

Technical Objectives and Opportunities:

-- Priority 1 --

Laboratory upgrades would provide significant capabilities for new polymer research at the molecular level, heteroatom polymer synthesis and characterization, characterization of polymers for electronics, etc. Focused centers would be established for the development of a) a new generation of polymers for electronics, optical, and magnetic applications, and b) composite materials with unprecedented toughness and high temperature capabilities.

-- Priority 2 --

The proposed expenditures would greatly enhance research in the areas of composite materials, ordered structural polymers, and polymer thin films for electronics applications. This in turn would lead to the development of improved dielectrics, capacitors, and electroactive polymers for uses such as piezoelectric sensors.

National Security Consequences: Polymer materials are essential elements of virtually all strategic and tactical weapons systems. High temperature metal matrix and ceramic matrix composites for applications such as radiation-hardened structures and gas turbine blades require high temperature fibers. Other applications include cheap, expendable acoustic detectors for sonic buoys, and a variety of electronic microdevices. Improvements in polymeric materials would enhance the performance, reliability, and maintainability of a wide array of weapons systems and logistics equipment.

ELECTRONICS

Thrust Area: Microelectronic Fabrication and Reliability for Unique DOD-Critical Devices/Materials

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 --	
New construction	60,000	30,000
Renovation/expansion	60,000	15,000
	-- Priority 2 --	
New construction	---	---
Renovation/expansion	20,000	4,000
Subtotal:	140,000	49,000

Equipment: Vacuum and plasma deposition; electron beam and x-ray lithography; plasma etching; wet chemical etching; impurity analysis with electron and ion beams; computational support for device modelling and process simulation; environment simulators for temperature, humidity, vibration, and synchrotron light source for surface diagnostics.

Priority	Cost ($ thousands)
1	30,000
2	6,000
Subtotal:	36,000

Total Cost: $85,000,000

Technical Objectives and Opportunities:

-- Priority 1 --

Provide vibration-free facilities for extremely small feature-size (one hundred angstrom) micro-circuit fabrication of devices utilizing technology beyond VHSIC. Electron-beam and x-ray lithographic equipment and plasma and laser enhanced photo deposition apparatus are required. Electron and ion-beam imaging systems for measurement analysis of ultra small structures are necessary.

-- Priority 2 --

Establish research capability in reliability of micro-circuit devices, especially with respect to temperature, humidity, and radiation hardness of ultra small devices. Expand synchrotron analysis capability for analysis of electrical contacts and other natural interfaces.

National Security Consequences: Integrated circuit fabrication is pressing the limits of our knowledge of chemistry and physics, particularly of interfaces between materials, and the utilization of unique materials for DOD devices. Research to provide the knowledge required for further advances in integrated circuits can only come if researchers in university laboratories have access to state-of-the-art fabrication equipment and processes. Reliability of military systems using integrated circuits depends to a large extent on the processes used to fabricate circuits and their stability over time.

ELECTRONICS

Thrust Area: System Robustness and Survivability

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost $ thousands)
	-- Priority 1 --	
New construction	---	---
Renovation/expansion	10,000	4,000
	-- Priority 2 --	
New construction	---	---
Renovation/expansion	5,000	2,000
Subtotal:	15,000	6,000

Equipment: Electromagnetic generators; anechaic chambers; microwave measurement equipment; propagation ranges; computation facilities for modelling and diagnostics.

Priority	Cost ($ thousands)
1	3,000
2	2,000
Subtotal:	5,000

Total Cost: $11,000,000

Technical Objectives and Opportunities:

-- Priority 1 --

Expand existing facilities for the measurement of electromagnetic propagation, measurement, and system network investigations.

-- Priority 2 --

Provide computational facilities to enhance modeling of electromagnetic interference phenomena.

National Security Consequences: Sophisticated weapon systems are potentially vulnerable to electro-magnetic interference, either consciously induced by enemy forces or unintentionally introduced through radiation from friendly force equipment. Subtle interactions between electronic systems operating on the same platform can degrade performance or completely deny weapon systems availability. Fundamental scientific understanding of means for minimizing these effects is required to supplement the current engineering fixes being pursued.

ENGINEERING

Thrust Area: Combustion

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 --	
New construction	57,500	9,250
Renovation/expansion	95,000	8,600
	-- Priority 2 --	
New construction	---	---
Renovation/expansion	9,300	1,250
Subtotal	161,800	19,100

Equipment: Variable high-pressure flow reactors; optical diagnostic instrumentation; chemical analysis instrumentation; vector processors for the simulation of turbulent multiphase processes; dedicated computer diagnostic and analysis capabilities.

Priority	Cost ($ thousands)
1	15,000
2	11,750
Subtotal	26,750

Total Cost: $45,850,000

Technical Objectives and Opportunities:

-- Priority 1 --

Conduct research on improving the energy efficiency of turbine and internal combustion engines, investigate the viability of alternate fuels (e.g., methanol), develop insights into high-pressure, high-temperature combustion chemistry of present and future propulsion fuels, study multiphase turbulent reacting fuels, and observe high altitude and high mach number combustion processes.

-- Priority 2 --

Develop unique facility for studying combustion and plasma phenomena of propulsion systems; anticipated benefits include increased understanding of ramjet and rocket motor instabilities, fire propagation phenomena ignition and flame propagation mechanisms, and plasma/gas dynamic interactions. Upgrade facility for quantitative flow field imaging to advance understanding of phenomena underlying energy conversion, aerodynamics, and propulsion processes.

National Security Consequences: Improve the range, performance, and reliability of aircraft, missile, ship, and land vehicle propulsion systems; enhance payloads, lower operating costs, reduce corrosion and detectable exhaust signatures, increase fuel performance, and reduce engine development time.

PHYSICS

Thrust Area: Coherent Radiation Sources

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 --	
New construction	---	---
Renovation/expansion	17,000	2,500
	-- Priority 2 --	
New construction	---	---
Renovation/expansion	---	4,000
Subtotal:	17,000	6,500

Equipment: Tunable two-beam two-stage free electron lasers; millimeter range free electron laser; mode-locked laser and support equipment; spectrographs for optical emission spectroscopy; electronic processing equipment (lithographic, deposition, etching); auxiliary interface and support equipment.

Priority	Cost ($ thousands)
1	1,500
2	6,250
Subtotal:	7,750

Total Cost: $14,250,000

Technical Objectives and Opportunities:

-- Priority 1 --

Laser facilities are key assets for a variety of materials and directed energy related research. The cited expenditures would substantially enhance the capability of universities to explore and expand technology horizons in electronic materials, catalysis, corrosion, and molecular biology, among others. Emphasis is on more broadly tunable lasers, which generate coherent radiation over a wide range of energies. This greatly enhances the flexibility available to researchers for analyzing material properties, particular surfaces, and interfaces of importance to solid state electronics and optoelectronics.

-- Priority 2 --

Laser-guided plasma and electron beam facility upgrades will allow the university community to explore more efficiently and comprehensively heretofore unknown aspects of directed energy propagation concepts.

National Security Consequences: Coherent radiation research is critical to a variety of DOD R&D missions, including the design of directed energy weapons, propagation (e.g., "channeling") of charged particle beams, improvement of high power radar technology and electronic countermeasures, advances in ultra-small electronic devices, optical storage and switching aspects of ultra-fast optical computers, etc. High average moderate power tunable lasers are expected to have important implications for tactical applications related to electronic warfare.

National Security Consequences: Advances in astrophysics-related imaging techniques have important applications for the detection and identification of space and non-space objects of military significance. In particular, the technological development of active optics in combination with speckle imaging will make possible diffraction limited observations of objects through the atmosphere. The enhancement of x-ray instrumentation capabilities has application to the detection of nuclear events in space.

PHYSICS

Thrust Area: Astrophysics

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 -- N/A	
	-- Priority 2 --	
New construction	68,000	11,550
Renovation/expansion	35,000	5,100
Subtotal:	103,000	16,650

Equipment: Radio, optical, and x-ray astronomy equipment; upgrade of 100 inch aperture telescope for active optics and interferometric imaging; high angular resolution imager with one milliarcsecond resolution and optical elements of 7 1/2 meters; 4-meter telescope for optical/infrared imaging and spectroscopy.

Priority	Cost ($ thousands)
1	N/A
2	152,065*
Subtotal:	152,065

Total Cost: $168,715,000

* Includes $150,000,000 for high angular resolution imager.

Technical Objectives and Opportunities:

-- Priority 1 --

N/A

-- Priority 2 --

- Expand laboratory capabilities in radio, optical, and x-ray astronomy to study final stages of evolution of stars, formation of neutron stars and black holes, the occurrence of supernova, and to elucidate recently observed non-thermal radio sources.

- Extend existing capabilities in active optics, speckle imaging techniques, and advanced detector programs to existing telescope to produce diffraction-limited imaging of astrophysical sources.

- Establish high angular resolution imager center which exploits advances in optics, sensors, and computer technology to afford a hundred-fold increase in image sharpness on celestial objects (quasar nuclei, stellar, and solar system object surface features) and space vehicles.

- Develop new optical and infrared telescope/instrumentation for astrophysics applications embodying improved precision pointing and tracking, image quality optimization, advances in optical and infrared technology, high speed two-dimensional photon detectors, etc.

Thrust Area: Structural Composites

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 --	
New construction	50,000	15,000
Renovation/expansion	60,000	8,000
	-- Priority 2 --	
New construction	---	---
Renovation/expansion	80,000	10,000
Subtotal:	190,000	33,000

Equipment: Vapor deposition epitaxy reactors; filament winders; squeeze casting presses; injection molding presses; textile forming looms; thermoforming presses; servo-hydraulic forming equipment; powder processing and fiber growth equipment; special equipment for ceramics processing; high temperature/high pressure autoclaves; process control computers; diagnostic and modeling computers and graphics.

Priority	Cost ($ thousands)
1	20,000
2	20,000
Subtotal:	40,000

Total Cost: $73,000,000

Technical Objectives and Opportunities:

-- Priority 1 --

Establish four major university centers of excellence in the fabrication of fiber and matrix materials, emphasizing polymer matrix and ceramic matrix materials. Capabilities should include fabrication and layup of small samples and diagnostic materials for the analysis of thermophysical and thermomechanical properties.

-- Priority 2 --

Supplement the above with three to four additional university centers with similar missions.

National Security Consequences: Lightweight and high strength composite materials are increasingly being used in aircraft and spacecraft. These materials combine the high strength of ceramic fibers with the ductility of polymeric or metallic matrices. Significant performance advantages have already been obtained through the use of composite materials, including ceramic matrix composites, and further performance advantages are foreseen, particularly with regard to high temperature capability, laser hardness, armor, and low observables.

MATERIALS

Thrust Area: Structural Ceramics

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 --	
New construction	20,000	3,000
Renovation/expansion	5,000	1,000
	-- Priority 2 --	
New construction	30,000	5,000
Renovation/expansion	10,000	2,000
Subtotal:	65,000	11,000

Equipment: Ball milling and mixing equipment; hot isostatic presses; vacuum and controlled atmosphere furnaces; fume hoods; surface analysis equipment; scanning electron microscopes; secondary ion mass spectrometers; x-ray diffractometers; computational facilities for data acquisition and process modelling.

Priority	Cost ($ thousands)
1	9,800
2	5,400
Subtotal:	15,200

Total Cost: $26,200,000

Technical Objectives and Opportunities:

-- Priority 1 --

Three university laboratories currently involved in ceramics research would be upgraded. The primary benefits include enhanced understanding of the fundamental relationships between (a) ceramics constituents and processing techniques, and (b) material properties, reproducibility, and reliability. Elucidation of these governing factors should greatly reduce the time required to develop improved ceramic materials and composites. Principal research benefits envisioned include development of non-destructive evaluation techniques, methods for the deposition of ceramic coatings using plasma techniques, and development of materials which will tolerate severe thermal shock and sustained high temperatures, and which have uniform, reproducible microstructures.

-- Priority 2 --

Three additional laboratory facilities would be expanded in the context of the above rationale.

National Security Consequences: In hostile environments, metal surfaces oxidize, corrode because of stress, fail because of fatigue, exhibit effects from laser radiation and interfacial phenomena, and are subjected to friction and wear. Ceramic materials are used in extremely hostile environments in turbine engines, rocket nozzles, and electromagnetic windows of high velocity aircraft and missiles.

MATERIALS

Thrust Area: Silicon and Compound Semiconductor Growth

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 --	
New construction	20,000	15,000
Renovation/expansion	40,000	8,000
	-- Priority 2 --	
New construction	---	---
Renovation/expansion	40,000	10,000
Subtotal:	100,000	33,000

Equipment: Molecular beam epitaxy; metal organic chemical vapor deposition electron beam diagnostics; laser probe diagnostics; mass spectrometry.

Priority	Cost ($ thousands)
1	30,000
2	10,000
Subtotal:	40,000

Total Cost: $73,000,000

Technical Objectives and Opportunities:

-- Priority 1 --

Crystal growth facilities for low defect silicon and for device quality gallium arsenide and gallium aluminum arsenide are required. Instrumentation in this area combines growth with evaluation of materials within the same deposition chambers. By contrast, in commercial practice crystal growth of bulk ingots is performed in an activity separate from the evaluation of the grown material. These facilities are extremely expensive and are in the laboratory apparatus phase currently, with few commerical instruments being available.

-- Priority 2 --

Crystal growth facilities for advanced compound semi-conductors such as mercury cadmium telluride are required for the improvement of optical as well as electronic devices. Relatively little research has been done on the application of modern growth techniques to these compounds, largely because of the attention focused on silicon and gallium arsenide.

National Security Consequences: Integrated circuits are at the heart of most modern military systems, from command and control to smart weapons. The VHSIC program has made a major advance in the capability of these devices, by reducing the feature size down to the one micron regime. Future advances in this circuitry will require greater fundamental understanding of the functioning of conventional integrated circuits. For feature sizes even smaller than this, quantum effects will introduce wholly new device phenomena, presenting major opportunities for advancement in information processing capabilty. Examples of technology applications include infra-red focal plane array detectors, integrated optics, millimeter and microwave integrated circuits, and optoelectronics.

MATERIALS

Thrust Area: Optical and Magnetic Materials

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 --	
New construction	10,000	3,000
Renovation/expansion	15,000	2,000
	-- Priority 2 --	
New construction	---	---
Renovation/expansion	10,000	2,000
Subtotal:	35,000	7,000

Equipment: Preparation and handling facilities; high vacuum furnaces; computer-controlled annealing ovens; fiber extrusion and cladding apparatus; grinding and polishing equipment; electron beam microscopes; laser diagnostic facilities; secondary ion mass spectrometers; electron spectrometers; Raman surface spectrometers; high field magnets; casting/grinding/magnetic aligning/sintering equipment operating in "oxygen-free" atmospheres.

Priority	Cost ($ thousands)
1	2,300
2	1,000
Subtotal:	3,300

Total Cost: $10,300,000

Technical Objectives and Opportunities:

-- Priority 1 --

Establish two university centers of excellence in optical materials for both fiber-optic applications and integrated optics circuits for signal processing. Facilities should include material growth, device fabrication, and evaluation capabilities. The centers would generate benefits in such DOD high pay-off areas as durable low loss fibers, laser sources in the ultra-violet and visible wavelength ranges, detectors in the 8-14 micron region, vapor processing/deposition processes, non-linear optical materials, etc.

-- Priority 2 --

Expand existing capability in magnetic materials for improvements in field strength and in temperature operating range of rare earth magnet materials. Research emphasis would be on materials characterization and structure definition using Mossbauer, x-ray diffraction, scanning transmission electron microscope, and neutron diffraction methods.

National Security Consequences: Optical materials are assuming greater significance to defense systems for surveillance, laser designation, and high energy laser weaponry. In addition, optical signal processing may provide an alternate to conventional integrated circuits for information processing. Magnetic materials are currently used in microwave transmitting devices, switching devices, and in non-volatile memory systems for crucial military information processing and communciation systems.

ENGINEERING

Thrust Area: Soil Mechanics

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 -- N/A	
	-- Priority 2 --	
New construction	6,000	1,600
Renovation/expansion	---	---
Subtotal	6,000	1,600

Equipment: Four hundred G-ton centrifuge with support apparatus.

Priority	Cost ($ thousands)
1	N/A
2	200
Subtotal	200

Total Cost: $1,800,000

Technical Objectives and Opportunities:

-- Priority 1 --
N/A

-- Priority 2 --
The centrifuge would permit the study of soil and structure phenomena in realistic stress regimes not possible with present facilities. The laboratory would be developed to study both static and dynamic loadings.

National Security Consequences: Research would be applicable to the development of improved structures for missile silos and hardened tactical facilities.

factors problems associated with the workload of single pilots in a high performance rotorcraft, stability and control research, and combustion studies aimed at enhancing engine performance.

-- Priority 2 --

Factory of the future concepts would be explored combining manufacturing physics and artifical intelligence, with emphasis on the development of unmanned, self-diagnostic, and self-repairing machines and robots.

Upgrades of two more rotorcraft laboratories addressing the technical issues outlined for Priority 1 would be made possible, with emphasis on rotorcraft dynamics and avionics, respectively.

National Security Consequences: Procurement and maintenance cost-containment are key considerations in the DOD budget. The proposed facilities would support research directed toward these goals. Improved quality control would enhance product reliability. Army mobility rests to a great extent on rotorcraft (helicopter) performance capabilities, including speed, lift capacity, payload, and crash-worthiness. The proposed facility expenditures would address all of these factors in a much more comprehensive manner than is now feasible.

ENGINEERING

Thrust Area: Manufacturing, Design, and Reliability

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 --	
New construction	77,000	9,250
Renovation/expansion	55,000	6,250
	-- Priority 2 --	
New construction	10,000	1,200
Renovation/expaansion	20,000	4,500
Subtotals	162,000	21,200

Equipment: Hardware and software for design of component inspectability and manufacturing process control functions; integration of advanced non-destructive testing capabilities with computer-aided mechanical design methods; modernization of dynamic track facility including electronic sensors and displays, simulators, and noise and vibration sensors; human factors diagnostic equipment; avionics gear; combustion diagnostic equipment.

Priority	Cost ($ thousands)
1	10,000
2	3,000
Subtotal	13,000

Total Cost: $34,200,000

Technical Objectives and Opportunities:

-- Priority 1 --

Advances in manufacturing methods having DOD-wide implications for reducing weapons system life-cycle cost, and for enhancing systems reliability, would be pursued. Ancillary objectives include reduced lead times and product development costs, improved productivity and quality control, and reduced inventory costs. A new, unique interdisciplinary manufacturing technology facility emphasizing optimal materials utilization and product reliability would be established. Emphasis would be placed on applications of artificial intelligence concepts to the manufacturing cycle. A second laboratory would be developed for studying the application of computers to the design, manufacture, and control of complex systems, and for the development of advanced composite materials.

Integrated, coordinated research into all aspects of rotorcraft design, manufacturing, and performance at two laboratories is a second objective of the proposed expenditures. Areas of concentration include computer-aided design and manufacturing of rotorcraft components, the study of human

and its impact on vehicle drag, and b) low turbulence flow phenomena with emphasis on associated viscous effects, leading to improvements in aircraft design and control technology.

-- Studies of nonlinear surface wave mechanics to enhance understanding of wave/wave/current interactions, ocean wave/ship wake interaction processes, and associated underwater acoustics, leading to improvements in ship designs, wake signature reduction, etc.

-- Integrated physical acoustics laboratory to facilitate research in sound propagation and attenuation, molecular and chemical physics, and underwater acoustics.

National Security Consequences: The proposed facilities enhancements would support research critical to improved aircraft performance, range, payload, and fuel efficiency. Defense applications of water tunnel upgrades include improved range and performance of ships (surface and submersible), reduction of noise signatures of submarines, and enhanced performance of acoustic sensors through the reduction of host-sensor interference.

ENGINEERING

Thrust Area: Fluid Mechanics and Acoustics

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 --	
New construction	---	---
Renovation/expansion	7,000	650
	-- Priority 2 --	
New construction	---	---
Renovation/expansion	---	350
Subtotals	7,000	1,000

Equipment: State-of-the-art instrumentation for physical acoustics research including highly stabilized lasers, cryogenic equipment, and digital processing gear for automating signal detection and data processing; instrumentation and support equipment for wind and water tunnel facilities for the upgrading of data acquistion and reduction capabilities. For water tunnels, traverse mechanisms, non-linear wave generators, current generators, and related measuring instruments are needed. Wind tunnel requirements include a multi-axis, three-dimensional laser doppler anemometer, and equipment for generating oscillatory flows.

Priority	Cost ($ thousands)
1	3,600
2	3,350
Subtotal	6,950

Total Cost: $7,950,000

Technical Objectives and Opportunities:

-- Priority 1 --

-- Wind tunnels facilities - provide a national resource for studying turbulent and unsteady flows in Reynolds number regimes typical of subsonic flight, and a second facility devoted to the study of the physics of separated flows and transitioning boundary layers. This research could lead to the development of revolutionary concepts of, and predictive methods for, flow management and control in the flight vehicle environment.

-- Water tunnel facility - upgrade an existing facility to greatly reduce flow noise inherent in present tunnel configurations. This improvement would facilitate research on reducing flow noise due to turbulent boundary layer flow around ship hulls.

-- Priority 2 --

-- Wind tunnel facilities - modifications at two sites to facilitate a) research on the prediction of the transition from laminar to turbulent flow

ENGINEERING

Thrust Area: Energetic Materials

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 --	
New construction	---	---
Renovation/expansion	---	1,000
	-- Priority 2 -- N/A	
Subtotals	0	1,000

Equipment: Mechanical and x-ray diagnostic devices; time-resolved optical spectrometer; electromagnetics effects sensor; gas guns; sample preparation equipment; specialized machine shops.

Priority	Cost ($ thousands)
1	7,000
2	---
Subtotal	7,000

Total Cost: $8,000,000

Technical Objectives and Opportunities:

-- Priority 1 --

A primary objective is the development of a broad class of high performance propellants. A second priority objective is research on energetic materials (explosives, propellants, etc.) which remain inert under shock conditions. This involves theoretical and experimental investigations of atomic and molecular processes in shocked condensed wave materials. Experimental research would provide time-resolved optical, x-ray, electrical, and mechanical diagnostics on materials stimulated by mechanical impactors or lasers.

-- Priority 2 --

N/A

National Security Consequences: Inadvertent ignition of explosives and propellants under mechanical shock and thermal stress is a significant operational hazard, particularly under combat conditions. The development of energetic materials which a) are relatively inert to those stresses, and b) function optimally on command, would mitigate this problem.

ENGINEERING

Thrust Area: Composite Structures

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 --	
New construction	---	---
Renovation/expansion	5,000	1,180
	-- Priority 2 -- N/A	
Subtotals	5,000	1,180

Equipment: Mechanical testing devices capable of multiaxial and variable loading rates in high temperature environments; real-time non-destructive ultrasonic, acoustic emission and x-ray radiography testing equipment; high temperature test equipment with associated data processing and dedicated computational capability.

Priority	Cost ($ thousands)
1	3,420
2	---
Subtotal	3,420

Total Cost: $4,600,000

Technical Objectives and Opportunities:

-- Priority 1 --

Composite materials have not been exploited to the degree possible, due to a lack of detailed understanding of their response to complex loading conditions, high strain rates, and hostile environments. The proposed facility would likely engender major advances in the understanding of the thermomechanical behavior and failure characteristics of composite materials, with emphasis on high temperature conditions.

-- Priority 2 --
N/A

National Security Consequences: Military applications of composite materials include engine hot sections, nozzles, missile nose cones, aircraft surfaces, lightweight high-strength materials, etc. Improved materials are key to enhancing the performance and maintainability of weapons systems and logistics equipment.

PHYSICS

Thrust Area: Directed Energy Devices

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 --	
New construction	---	---
Renovation/expansion	63,000	13,250
	-- Priority 2 --	
New construction	---	---
Renovation/expansion	20,000	4,000
Subtotal:	83,000	17,250

Equipment: Hardware to enlarge accelerator power supplies and capacitor banks; vacuum tube fabrication equipment; large electric discharge chambers; pulsed power generator; high-power glass laser; dedicated data acquisition and analysis computer facilities.

Priority	Cost ($ thousands)
1	6,250
2	4,000
Subtotal:	10,250

Total Cost: $27,500,000

Technical Objectives and Opportunities:

-- Priority 1 --

- Upgrade stellatron accelerator facility as a testbed for high current, high energy accelerators, including screen room and associated diagnostic instrumentation. Facility would generate data of use in the development of compact, high performance accelerators in the non-linear beam interaction regime.

- Establish center for research on thermionic sources of millimeter wave radiation at megawatt power levels. The facility would provide understanding electron-electromagnetic field interactions leading to the development of Rf sources in a regime extending to 30 THZ.

- Develop high repetition rate, high average power pulsed power facilities to support studies in plasma beam propagation, microwave power generation, and the interaction of electromagnetic radiation with materials.

-- Priority 2 --

- Expand center for research on switches and power conditioners for extremely high voltages and high currents. Research in this area is heavily dependent on the existence of specialized facilities.

National Security Consequences: Compact high current, high energy accelerators are key components in charged and neutral particle beam weapons concepts. Thermionic radiation sources are essential components of and/or have implications for fusion power sources, directed energy weapons, and spacecraft vulnerability questions associated with ion clouds in space. High voltage and high current switches, regulators, and storage devices are required to operate directed energy weapons. The development of repetitive and reliable opening switches would remove significant impediments to the practical implementation of all directed energy devices.

PHYSICS

Thrust Area: Optical Communications and Spectroscopy

Laboratory Needs

Facilities:	Building Requirements (gross ft^2)	Total Facility Cost ($ thousands)
	-- Priority 1 --	
	N/A	
	-- Priority 2 --	
New Construction	8,000	1,000
Renovation/expansion	---	---
Subtotal:	8,000	1,000

Equipment: Lasers (stable argon ion, ring, picosecond CO_2, femtosecond dye and YAG, mode-locked glass); transient digitizers; computational and digital signal processing capabilities; scanning electron microscope; optical components with special coatings.

Priority	Cost ($ thousands)
1	1,550
2	950
Subtotal:	2,500

Total Cost: $3,500,000

Technical Objectives and Opportunities:

-- Priority 1 --

Laboratory upgrade would facilitate research leading to a better understanding of the fundamental processes and interactions in semiconductors and microstructures necessary for the development of ultra-fast semiconductor electronic devices.

-- Priority 2 --

- Laboratory improvement would permit detection of weak signals which arise in many photon statistic experiments. For example, the creation of photon pairs through non-linear processes followed by subsequent simultaneous detection (i.e. correlation experiments) generally produces weak signals. Such phenomena could greatly expand communication signal detection capabilities.

- A Center for Optical Circuitry would be established for optical computing. It offers the possibility of great advances in computing speed, capacity, and degree of parallelism over electronic computing. Dramatic new computer architectures are possible, e.g., three-dimensional logic and storage.

National Security Consequences: A wide variety of defense-related technology improvements are based on progress in the development of extremely fast and compact electron devices for digital and analog applications. These include smart weapons and surveillance systems. In addition, secure optical communications have important applications to C3.

CHAPTER V

DISCUSSION AND RECOMMENDATIONS

A. DISCUSSION

The laboratory needs cited in Chapter IV relate to universities already heavily involved in conducting research for DOD. They represent a small subset of the 157 colleges and universities addressed in Tables III-4 and 5, and an even smaller segment of all research universities included in Tables III-2 and 3. The AAU study summarized in Table III-1 equates with this work most readily in terms of the number of institutions covered.

Summary comparisons follow between the prior laboratory assessments cited in Chapter III and the present work given in Chapter IV. It should be emphasized that these comparisons involve the DOD-specific laboratory needs developed in this report as opposed to more general needs addressed in prior studies. Nonetheless, they suggest that the cumulative expenditures discussed in Chapter IV are of reasonable magnitude in the context of general university laboratory needs identified in other studies.

- The AAU data shown in Table III-1 relate to 15 universities, a figure roughly equivalent to the average number of institutions encompassed by defense-related laboratory needs for each of the disciplines cited in Table IV-1. This probably accounts for the fact that, for some disciplines, defense-related totals substantially exceed the AAU report figures. Interpretations of these comparisons must be tempered by the fact that the discipline-specific university populations encompassed within the present study differ markedly from the AAU sample population. A Comparison of Tables III-1 and IV-1 indicates that the defense-related facilities needs cited in this report constitute 43 percent of the AAU Chemical Sciences projections for the period 1982-84, over 100 percent for Engineering (encompassing the Electronics, Engineering, and Materials categories of Table IV-1), and 55 percent for Physics. For projected equipment needs, those of this study exceed the AAU figures by factors of roughly three and six for Chemical Sciences and Engineering. The numbers are comparable for Physics, excluding the astrophysics high resolution imager cited in the present study.

- According to NSF staff, an estimated 50 percent to 70 percent of the $221 million cited in Table III-2 for 1983 university capital expenditures (research <u>and</u> instructional) was devoted to research laboratory facilities. Assuming, for purposes of comparison, a 60 percent figure, 1983 research laboratory expenditures for all universities in the engineering and physical science disciplines total $133 million. To obtain a roughly comparable figure, one can annualize the $275 million of defense-related engineering and physical sciences facilities needs (Table IV-1) over a five-year period. This yields an annual expenditure rate of $55 million. It represents slightly more than 40 percent of the estimated $133 million spent by all universities.

- o Research equipment expenditures for all U.S. colleges and universities are summarized in Table III-3 for Engineering, Chemistry, and Physics and Astronomy. Engineering expenditures average approximately $70 million for the two-year period. The NSF Engineering category compares roughly to the combined Engineering, Electronics, and Materials categories of this report, where priority 1 and 2 equipment needs shown in Table IV-1 total almost $200 million. If the $200 million is annualized over a five-year period, approximately $40 million in FY 85 dollars would be spent for defense-related equipment annually. This represents over 55 percent of the average 1982-83 engineering annual equipment expenditures for all higher education institutions. Similar analyses for physics and chemistry suggest that needs in these areas cited in Table IV-1 pro-rated over five years are approximately $35 million and $9.5 million, respectively. The projected annual physics expenditure is roughly equal to the NSF 1982-83 average for all universities, largely due to a $150 million high resolution imager for astrophysics. Similarly, the projected chemistry annual expenditures are 30 percent of the average for all U.S. universities for the two-year period.

- o Column two of Table III-4 lists 1982 research equipment expenditures for the top 157 research universities. As in Table III-3, the NSF Engineering category compares roughly to the combined Engineering, Electronics, and Materials categories of this report, whose equipment needs total approximately $200 million. Assuming again that expenditures for defense-related laboratory equipment needs would be spread over a five-year period, approximately $40 million in FY 85 dollars would be spent for this purpose annually. This represents roughly 45 percent of the 1982 expenditures for the 157 universities. Similarly, the five year annual expenditure level for physics from Table IV-1 is over 60 percent of the 1982 equipment purchase level, largely due to the inclusion of the aforementioned $150 million high resolution imager for astrophysics applications. The five-year expenditure level implied for chemistry in Table IV-1 is $9.5 million, or approximately 25 percent of the stated 1982 expenditures by the 157 universities.

- o The replacement value of "academic research instrument systems in active research use" for the aforementioned 157 universities is given in Table III-3 in terms of 1982 dollars (Column 4). With an inflation factor of 1.076 applied to the 1982 costs, Table V-1 gives priority 1 and 2 (total) defense-related equipment needs from Table IV-1 expressed as percentages of Table III-5 replacement values. As before, the NSF Engineering category encompasses the Electronics, Engineering, and Materials categories of this report. For the Engineering and Physics and Astronomy categories, stated defense-related needs are quite substantial in comparison with the NSF equipment replacement figures. The Chemistry percentage is substantially lower, perhaps reflecting a proportionately lesser DOD involvement in broad aspects of experimental chemistry.

Table V-I

Defense-related university laboratory equipment needs (Table IV-1) expressed as percentages of replacement costs for all research equipment at 157 leading research universities (Table III-5)

Field of Research	% of Replacement Value
Chemistry	15
Engineering	44
Physics and Astronomy	68

B. RECOMMENDATIONS

A total of $300 million over a five (5) year period is proposed for the upgrading of university laboratories.

1. The priority 1 laboratory facilities needs cited in Table IV-1 should be addressed with incremental funding of a five-year $150 million initiative. The initiative should be a part of, and administered through, the existing contract research programs of the OXRs and DARPA. It is believed that this is the most efficient mechanism for targeting facilities improvement funds toward the highest DOD research priorities. This program would be of equal magnitude (i.e. $150 million expended at an annual rate of $30 million) to the existing University Research Instrumentation Program (URIP) pertaining to equipment, but would be allocated as facilities-earmarked increments to competitive research awards. It would thus differ from URIP in that it would not require the establishment of separate review and award mechanisms. It should be stressed that, in the best interests of national security, neither equipment nor facilities upgrade programs should be funded at the expense of existing OXR and DARPA competitive research programs. Further erosion of the latter would jeopardize the scientific basis for future technological innovation on which our national security depends.

2. The existing URIP program should be extended by three years at its present level of $30 million per year. This, combined with the remaining two years ($60 million) of the present program, would constitute the $150 million required to address priority 1 equipment needs (Table IV-1).

3. Priority 2 laboratory needs should be addressed as a national issue with the involvement of other federal agencies having an impact on the national science and technology base, i.e. the National Science Foundation, NASA, Department of Energy, etc.

4. Very large items of equipment and/or facility needs, e.g. the $150 million astrophysics high resolution imager cited in this report, should be addressed on their merits as individual appropriations rather than as parts of broader, more general funding initiatives.

APPENDIX

APPENDIX

STUDIES OF ACADEMIC FACILITIES*

Study	Description of Study	Findings
"Health Related Research Facilities in the U.S. in the Nonprofit Nonfederal Sector" Study by Westat Corporation for National Institute of Health (NIH) (1969)	Survey study to gather data on the amount, age and ownership of space in 1968, the amount of space under or scheduled for construction and the estimated space needed to eliminate overcrowding by 1980	10 m. of 42 m. sq. ft. in unsatisfactory condition -over 50% available space in poor condition -additional 55 m. square feet of space needed by 1980, with 17 m. square feet requiring remodeling
"Higher Education General Information Survey" (HEGIS) Conducted by the National Center for Educational Statistics (NCES) (1974)	Survey of 3,200 colleges and universities including data to estimate facilities needs	-20% of facilities at surveyed institutions in need of replacement (2.3 billion square feet) -$2. billion needed just for remodeling of facilities
"Health Research Facilities: A Survey of Doctorate-Granting Institutions." Conducted by American Council on Education (ACE) with funding from National Science Foundation (NSF) and NIH (1976)	Survey of 155 Ph.D. granting institutions to gather data on status of academic health research facilities, new construction in progress, and plans for expansion in succeeding five year period	-29% of academic facilities for health research in need of renovation or replacement (23 million square feet) -cost estimates to meet needs: $547 million for 1975; $560 million for each of succeeding five years
"National Survey of Laboratory Animal Facilities and Resources" Conducted by National Academy of Sciences (NAS) (NIH Publication No. 80-2091) (1978)	Survey of 922 nonprofit NIH eligible institutions gathering data to estimate facilities needs	-16% institutions reported need for replacement of facilities -38% reported need for remodeling of facilities -47% reported need for additional space

*Source: Linda S. Wilson, "The Capital Facilities Dilemma: Implications for Graduate Education and Research", to be included in forthcoming Brookings Institution study, Bruce L. R. Smith, editor, The State of Graduate Education, 1985.

STUDIES OF ACADEMIC FACILITIES

Study	Description of Study	Findings
Report of Research Facilities Branch of National Cancer Institute on survey of facilities needs in cancer research Conducted at request of National Cancer Advisory Board (1979)	Survey of 106 institutions receiving National Cancer Institute Support gathering data to evaluate current and future needs for upgrading of cancer research facilities	Funding need of $149 million for the period 1980–1985 estimated for cancer research facilities
"A Program for Renewed Partnership" Prepared by the Sloan Commission on Higher Education (1980)	Commission report on federal government/university relations (No data collected)	-Recommendations for competitive program for facilities research grants; $50 million annually for five years, to be allocated by NSF and NIH, to upgrade research laboratories and equipment
"The Nation's Deteriorating Research Facilities: A Survey of Recent Expenditures and Projected Needs in Fifteen Universities" Conducted by the Association of American Universities (AAU) (1981)	Survey of 15 leading universities gathering data on expenditures for research facilities and major equipment and estimates of funding needs for succeeding three year period for faculty research only	-From 1972-1982, surveyed institutions spent $400 million for facilities construction, repair, and renovation -$765 million needed for facilities and equipment over succeeding three year period just to sustain faculty research activities

STUDIES OF ACADEMIC FACILITIES

Study	Description of Study	Findings
Report on academic facilities survey (in 1980-81 Comparative Cost and Staffing Report) Conducted by Association of Physical Plant Administrators (APPA) (1981)	Survey of 226 institutions with 454 million square feet of academic space to gather data on facilities conditions and projected needs	-$1.85-$2.00/square foot required to eliminate most pressing needs -deferred maintenance need per institution of $9.5 million at universities $1.1 million at four year colleges $.4 million at two year colleges
"Strengthening the Government-University Partnership in Science" Conducted by Ad Hoc Committee of NAS, National Academy of Engineering and Institute of Medicine (1983)	Committee report on federal government/university relations (no data gathered)	-Critical, growing need for replacement of academic science facilities and equipment -recommends comprehensive program for facilities construction and development, acquisition, maintenance and operation of modern equipment
"Adequacy of Academic Research Facilities" Conducted by Ad Hoc Interagency Steering Committee on Academic Research Facilities (April, 1984) National Science Foundation	Pilot study of 25 major research institutions with major study planned to gather data for detailed analysis of the condition of facilities used for science and engineering and medical research. Major study to estimate future needs for construction, remodeling and refurbishment of academic research facilities	-Over succeeding 5 year period all colleges and universities would require about $1.3 billion per year for research facilities alone. (Note: Present level of capital facilities expenditures for academic research, development and instruction is $1 billion per year.)

STUDIES OF ACADEMIC FACILITIES

Study	Description of Study	Findings
Report of Department of Defense (DOD) Working Group on Engineering and Science Education. Prepared by DOD-University Forum (1983)	Working group report on condition and needs of academic science and engineering	Deficiencies in research facilities and equipment acute in most universities
"Report on NIH Experience with Extramural Construction Authority" Prepared by Office of Program Planning and Evaluation, NIH (1983)	Historical comparison of legislative authorities for construction of health research facilities analyzing past facilities funding experiences	-Funding authorities mainly for special, not general, use -Almost all funds made available under grant mechanisms -Recent authorities fail to separate funds for construction and research -None of funding authorities based on systematic analysis of need
"University Research Facilities: Report on a Survey Among National Science Foundation Grantees" Conducted by Division of Policy Research and Analysis, NSF, for Infrastructure Task Group of National Science Board (NSB) (June, 1984)	Survey of 1983 NSF grant Principal Investigators (248 investigators randomly sampled) to determine condition of existing facilities and the impact of facilities on research	-70% facilities had been renovated in last 10 years using 7% Federal \$ -50% facilities slated for renovation in next three years -80% of P.I.'s rated safety of facilities as excellent -60% reported having lost some research time in past year due to facilities-related failures; 40% reported graduate students had spent 3 or more days fixing problems created by facilities over past year

STUDIES OF ACADEMIC FACILITIES

Study	Description of Study	Findings
Proposed study of cancer research facilities Conducted by President's Cancer Panel and the National Cancer Institute (Proposed)	Proposed survey study to gather data to inventory the quality and quantity of current research facilities in cancer research	In progress
Facilities Needs in Chemical Science and Engineering Conducted under aegis of the Board on Chemical Science and Technology, National Research Council (In progress)	Survey to ascertain specific facilities data for research and teaching in chemistry, biochemistry, and chemical engineering academic departments	In progress